Report of the Precision Range Determination (PRD) Working Group

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ICESat Science Team Meeting
Boulder, CO
October 13-14, 2005

Precision Range Determination Working Group

Objective: Assess, validate, & document GLAS products in order to improve the determination of range used in geolocation, as well as estimation of slope & roughness

Products:
Transmit and Received Energies
Saturation Range Correction
Cloud Detection
Atmospheric Forward Scattering Range Correction
Alternate Waveform Fitting
Footprint Ellipticity and Size
Within-footprint Slope and Roughness

Approach:
(1) Examine assumptions, algorithms, and input parameters currently used in product generation
(2) Make additional laboratory calibration measurements where needed
(3) Revise algorithms and parameters as needed, given our now greater understanding of instrument performance and measurement characteristics
(4) Implement revisions in GSAS code
(5) Validate that the GSAS code properly computes the product
(6) Assess the accuracy of the reported product
(7) Document product derivation, validation and accuracy

Procedure:
Weekly telecon meetings (Wednesday's at 2 pm) - began 6/22/05
Action items assigned to individuals and status tracked
10 tasks with task leads and sub-groups report to the full PRD group

Precision Range Determination Working Group Tasks

Task 1. Transmit Pulse and Received Waveform Energy Estimation - X. Sun *

Task 2. Correction of Centroid Time Walk Caused by Saturation - X. Sun *

Task 3. Alternative Range for Saturated Returns: Leading-edge Timing

Task 4. Received Waveform Alternate Gaussian Fitting - D. Harding *

Task 5. GLAS pre-launch range offset measurements, using Gaussian timing estimates

Task 6. Cloud Detection & Atmospheric Forward Scattering Correction - C. Shuman *

Task 7. Catalog Anomalous Waveforms (The Zoo)

Task 8. Range Error Contribution to Geolocation Imprecision

Task 9. Footprint Ellipticity and Size Estimation - B. Schutz *

Task 10. Slope and Roughness Estimation from Waveform Broadening - D. Harding *

**** status report included***

Task 1 - Transmit Pulse and Received Waveform Energy Estimation
- Progress report, 10-13-05

Leaders: Xiaoli Sun and Donghui Yi

Primary Focus: Validate transmit energy, received energy and apparent reflectivity over full range of observed energies.

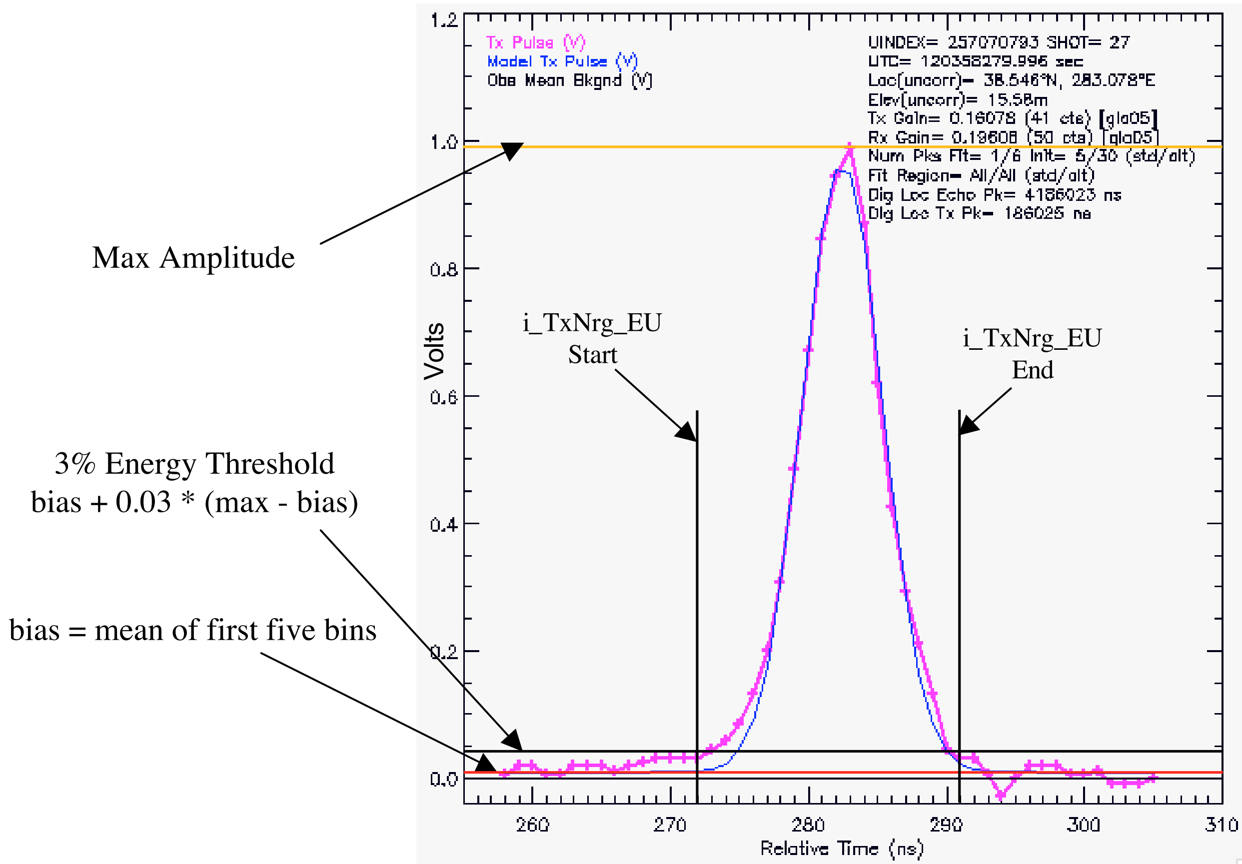
Approach:
(a). Transmitted laser pulse energy:
Compare the GLAS product with those by the Instrument team based on methods and calibration coefficients traceable to pre-launch testing.
(b). Echo pulse energy:
- Spot-check the GLAS product by “hand” (recalculate independently using the same formula but different software);
- Compare the effects of various approximation methods.
(c). Apparent surface reflectance
- Determining the optical losses due to bore-sight offset;
- Comparing the GLAS measured reflectance with the “ground truth” at a few calibration sites (e.g., White Sand, ocean reflection vs. wind speed.)

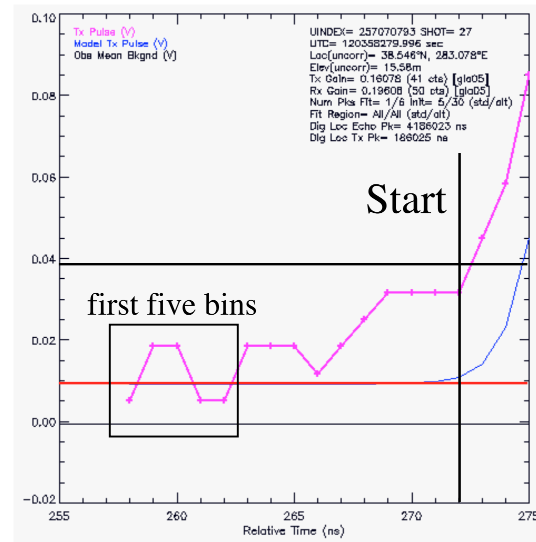
Status: (a)&(b), completed.

Remaining Work: Determine receiver optical transmission losses due to receiver bore-sight offset.

Schedule: TBD

Transmit Pulse Energy Calculation





<u>Energy = sum, in volts, of signal level above bias between energy start and end</u>

i_TxNrg_EU Start = first bin preceding the maximum amplitude peak where the signal is below the energy threshold

i_TxNrg_EU End = first bin following the maximum amplitude peak where the signal is below the energy threshold

<u>The effect of a small bias due to waveform truncation is included in the calibration coefficients.</u>

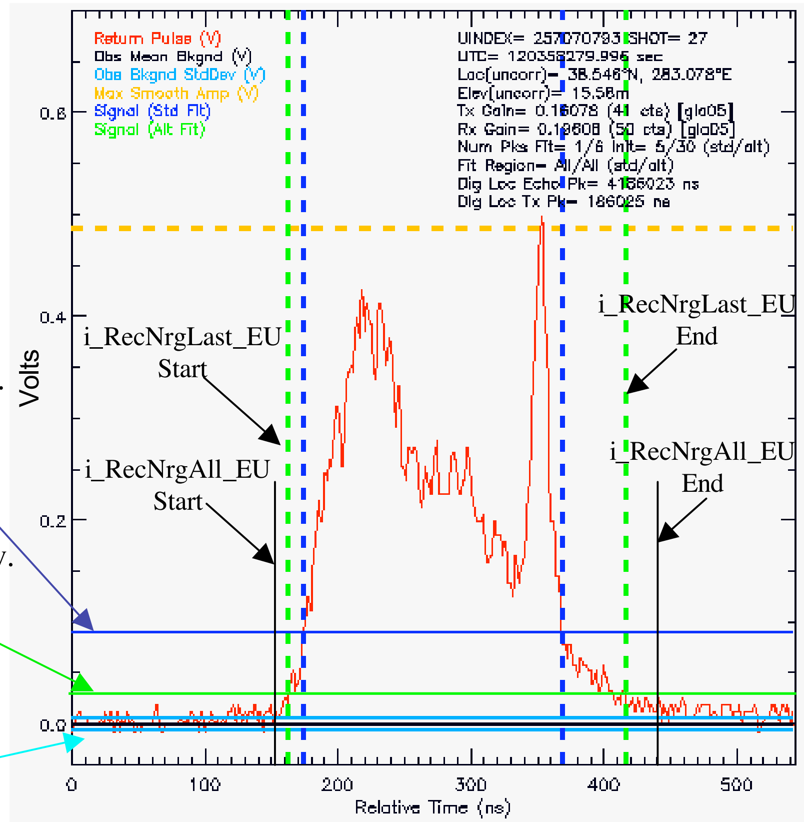
Echo Pulse Energy Calculations, Standard and Alternate

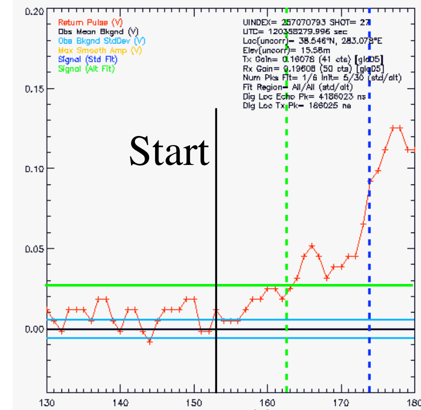
Alternate & energy threshold factors are not required to be equal in the ISIPS processing code,
but 4.5 is used for both beginning with Release 24

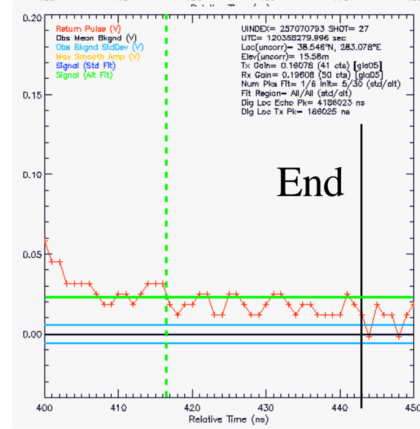
Standard Threshold
mean background+15 noise st. dev.

Alternate & Energy Threshold
mean background +4.5*noise st. dev.

The mean background and standard deviation of the noise is calculated from a sample of the receiver output acquired above the Earth's atmosphere.







<u>Energy = sum, in volts, of signal level above mean background between energy start and end</u>

i_RecNrgAll_EU Start = one bin after offset crossing prior to first crossing of energy threshold

i_RecNrgAll_EU End = one bin before offset crossing following last crossing of energy threshold

I_RecNrgAll energy will be slightly larger than the energy between alternate start and end

i_RecNrgLast_EU Start = energy threshold crossing prior to maximum amplitude peak

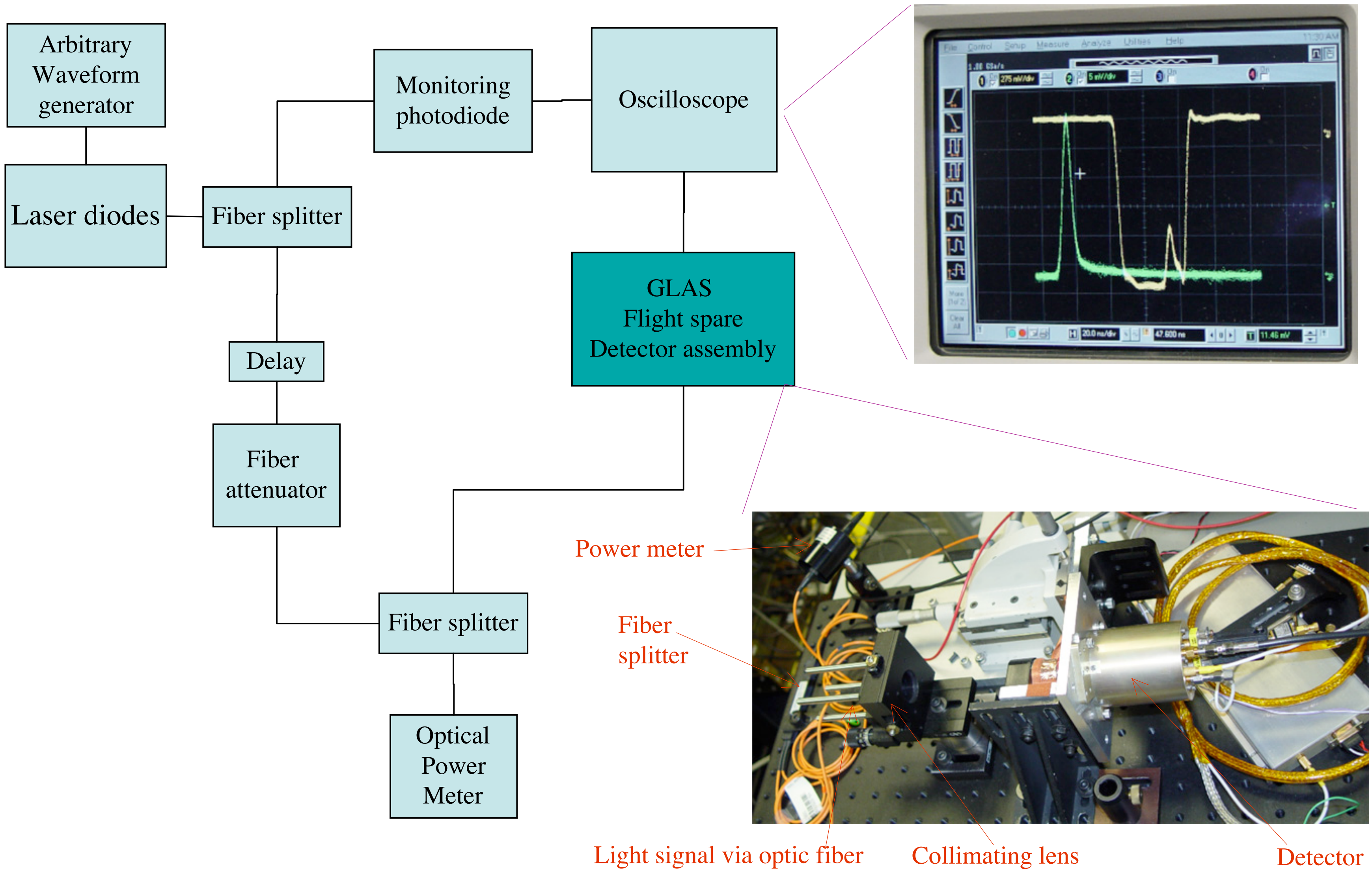
i_RecNrgLast_EU End = energy threshold crossing following maximum amplitude peak

"Last" is a holdover term; it is the energy from the threshold crossing preceding and following the maximum peak

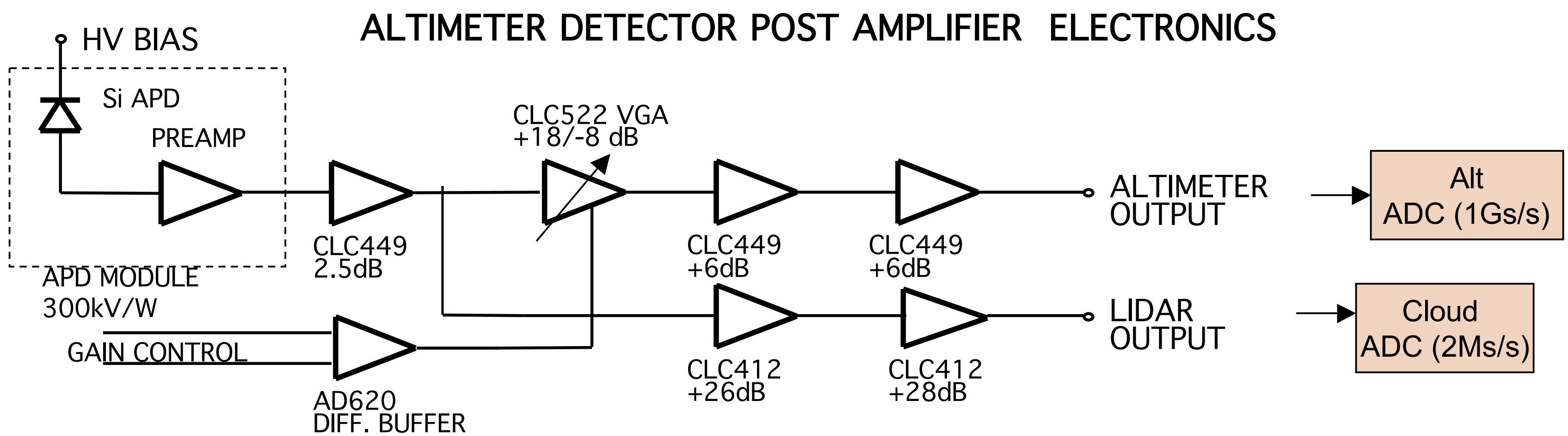
Task 2 - Correction of Centroid Time Walk Caused by Saturation

Leaders:	Xiaoli Sun, Donghui Yi and Helen Fricker
Primary Focus:	Icesheet saturated returns with <40 fJ received pulse energy
Approach:	(a). Derive a look-up table of range walk correction using the calculated echo pulse energy and the detector gain as indices based on the laboratory measurements; (b). Derive a model/formula to account for the slope effect
Status:	Lab measurements for flat surface completed, an initial look-up table derived, and saturation correction extended to severely saturated pulse waveforms (e.g., water surface).
Remaining Work:	Refine the 3-D surface fitting to the measurement data and develop an algorithm for pulse energy correction
Schedule:	To be completed by Dec. 31, 2005

Lab Measurement Setup



GLAS Detector Assembly Circuit, and Dynamic Range

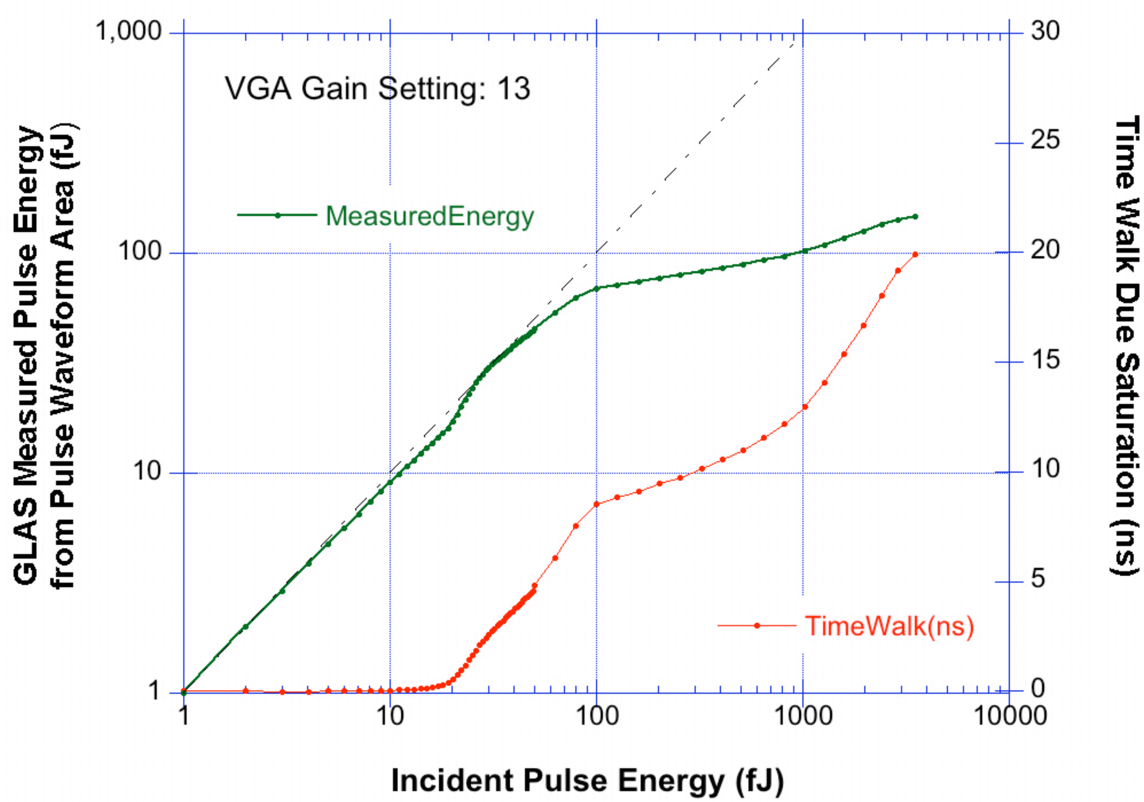


- The maximum receiver linear dynamic range is 13 fJ/pulse with the VGA gain properly adjusted.
- Saturation may occur at APD/preamplifier, VGA, ,post amplifier, or ADC, each with different characteristics
  - "Low gain saturation" at gain=13 is mainly caused by the Si APD preamp (2.0uW max pulse peak power) with the maximum pulse amplitude limited to ~220;
  - "Low gain saturation" at gain<13 is caused by VGA, with maximum pulse amplitude < 220
  - "High gain saturation" is mainly caused by the post amplifiers, with the maximum pulse amplitude <220 and decreasing with the VGA gain;
  - Some "High gain saturation" is caused by ADC, with the pulse waveform clamped at 255.

Lab Measurement Data

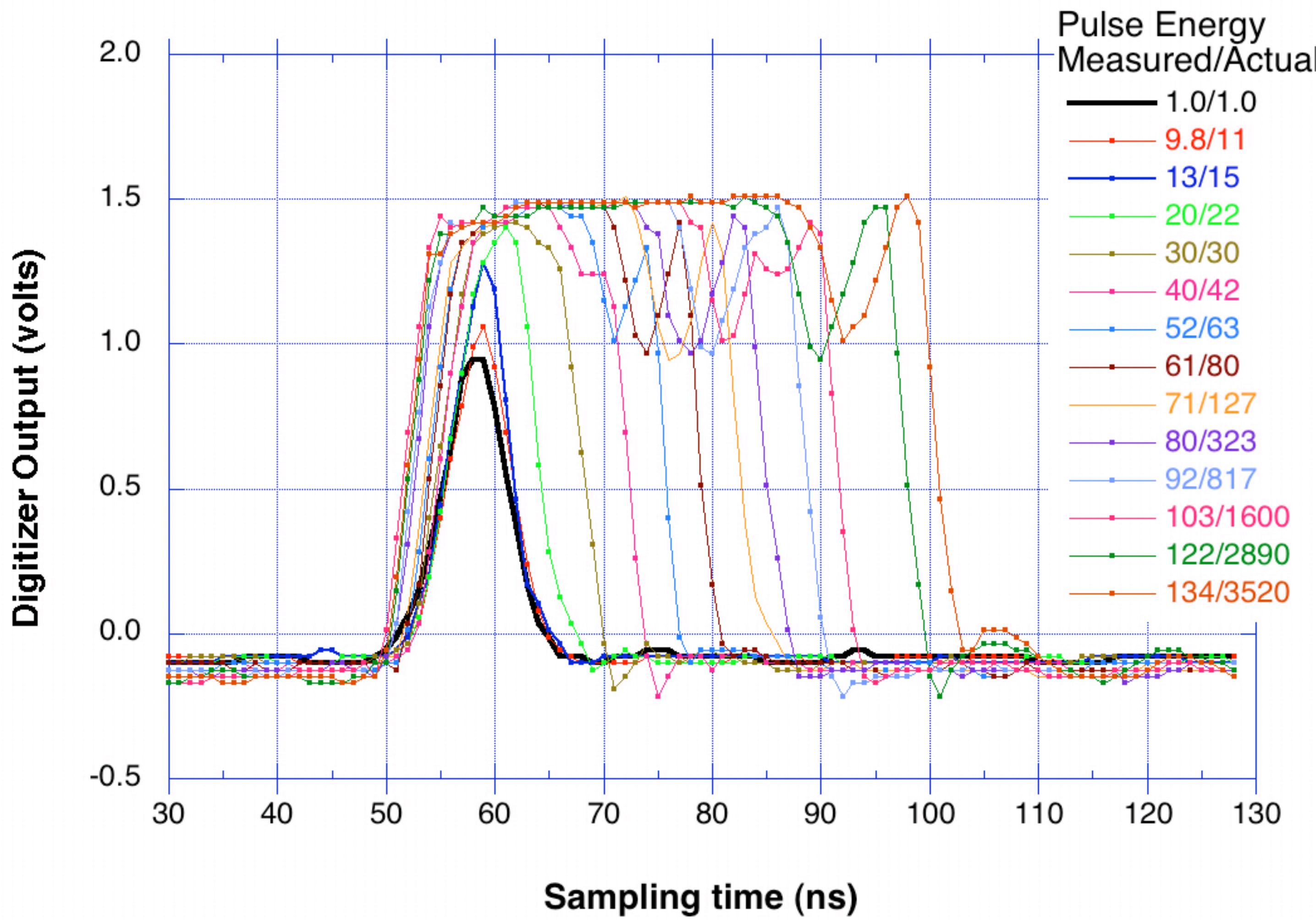
- GLAS measured pulse energy and "Time Walk" vs. Incident pulse energy at Gain=13

Measured with the Flight Spare Detector (SN-2) in the Lab

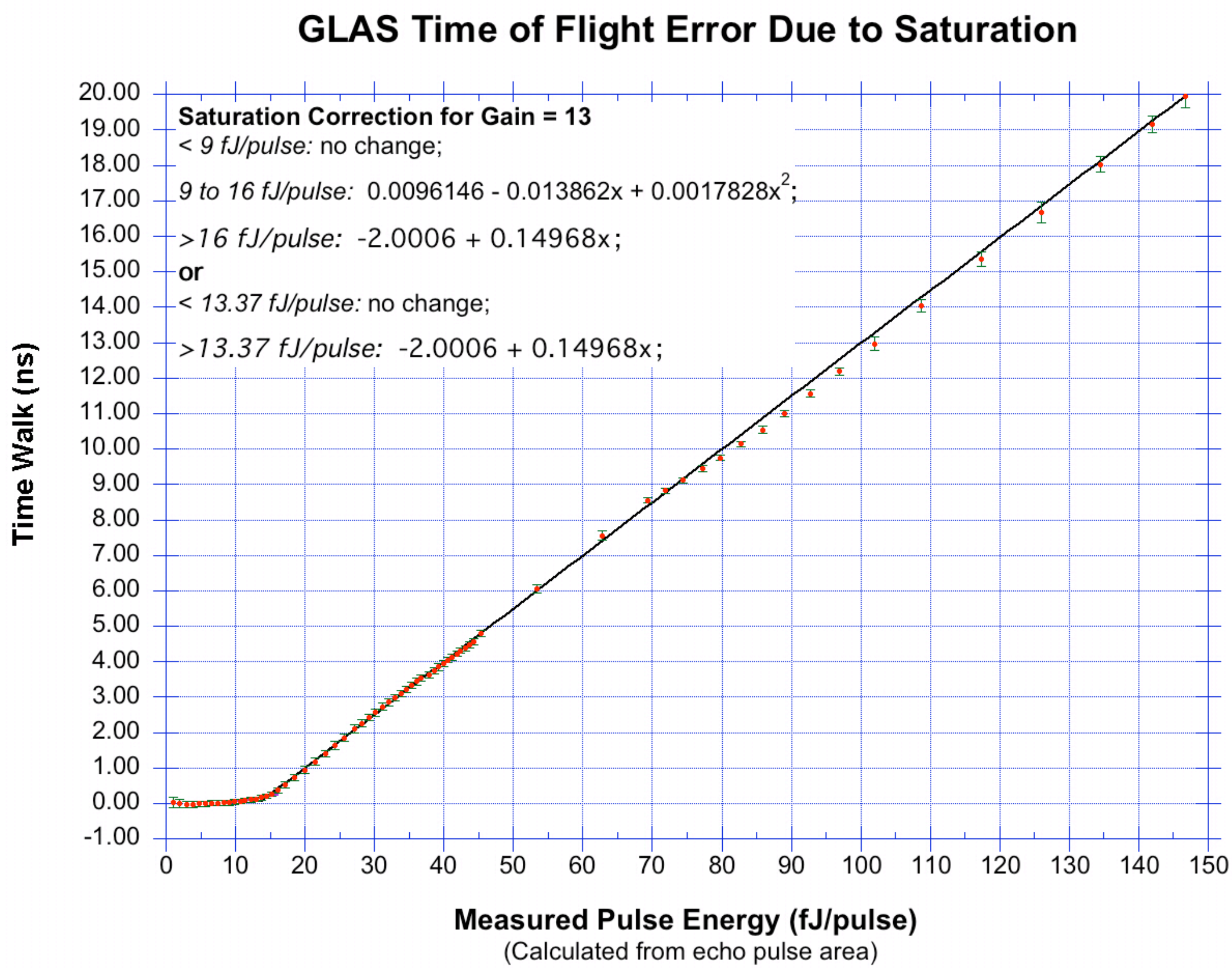


Note the actual incident pulse energy is not available in orbit and must be estimated from the the measured ones from the pulse waveform.

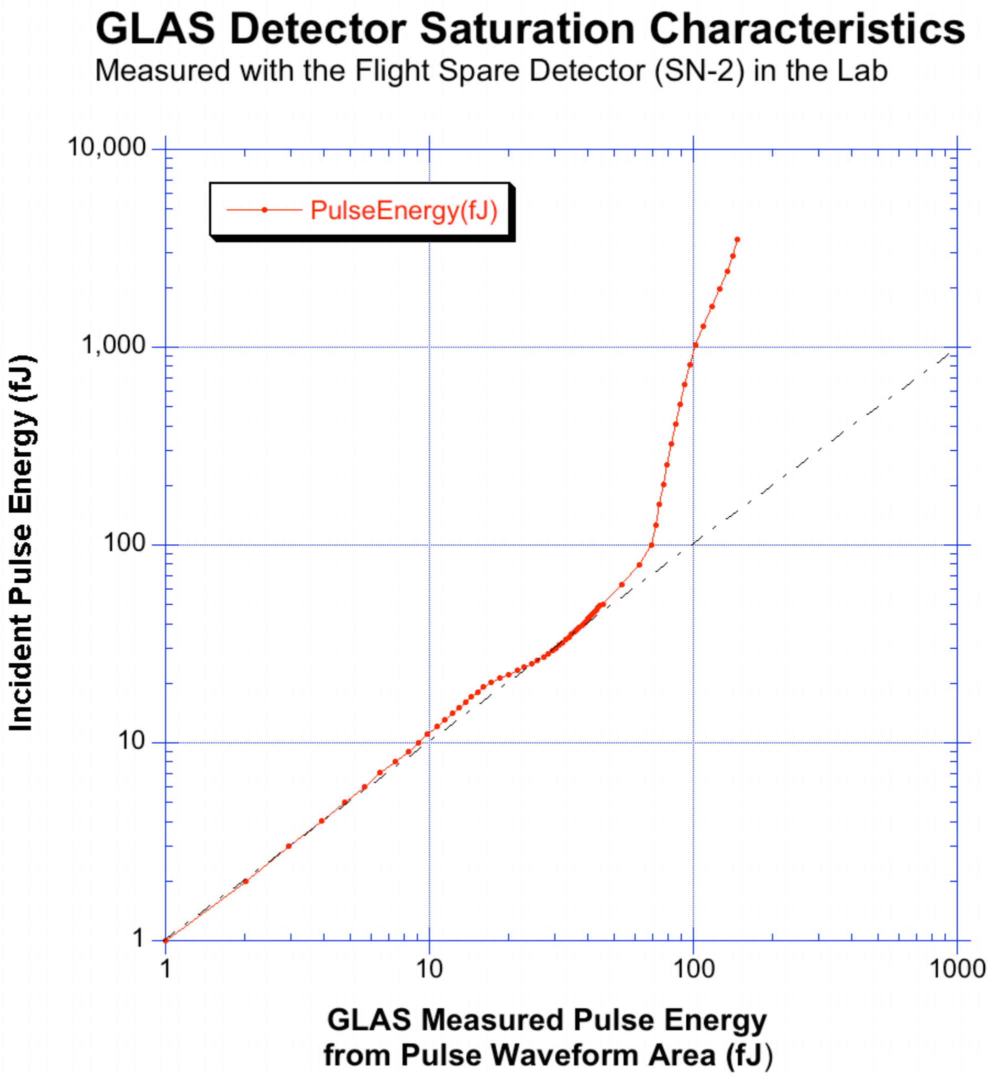
Sample Echo Pulse Waveforms at G=13



Time Walk as a Function of Measured Pulse Energy for Gain = 13

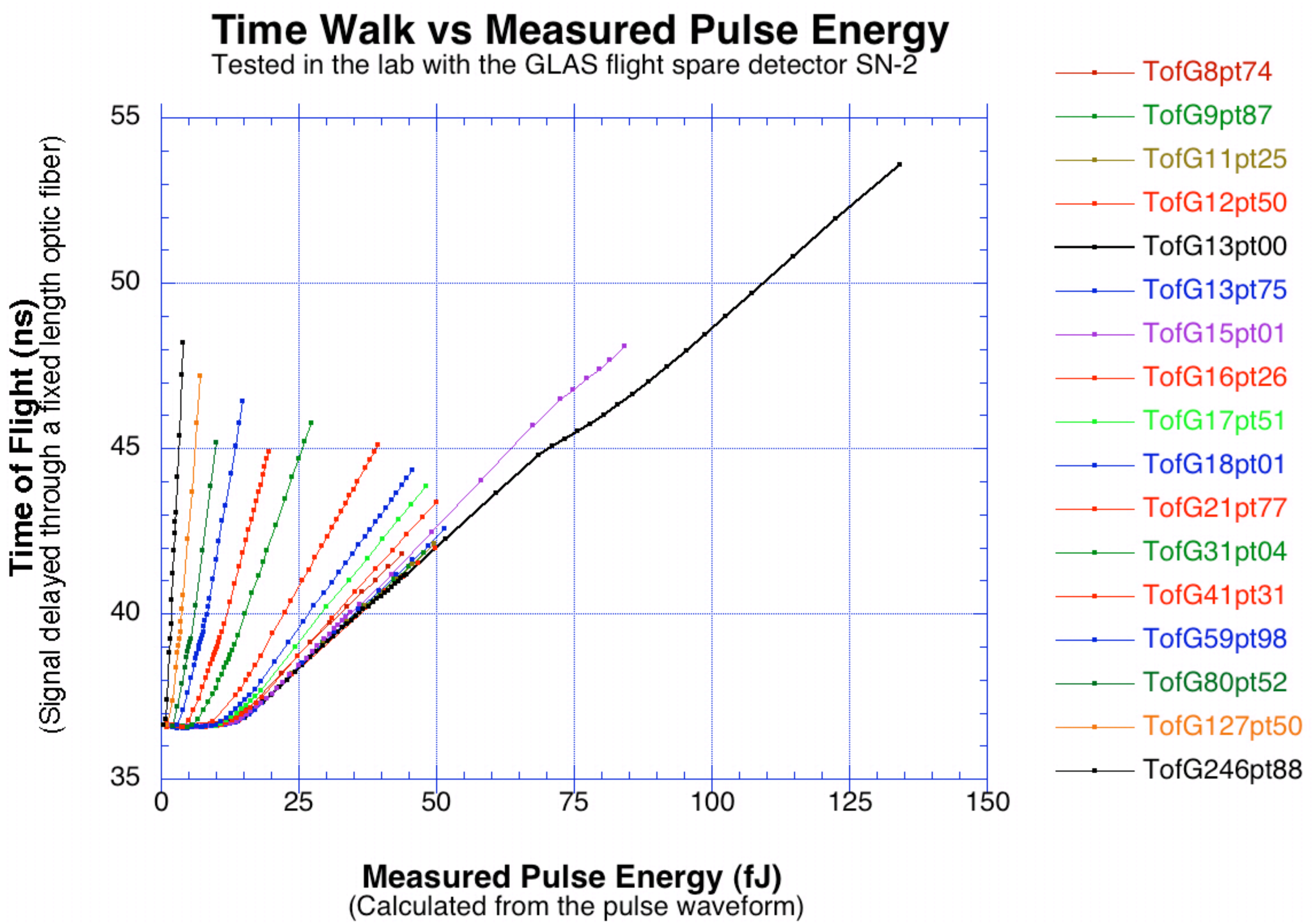


Incident Pulse Energy vs. Measured Pulse Energy for Gain=13

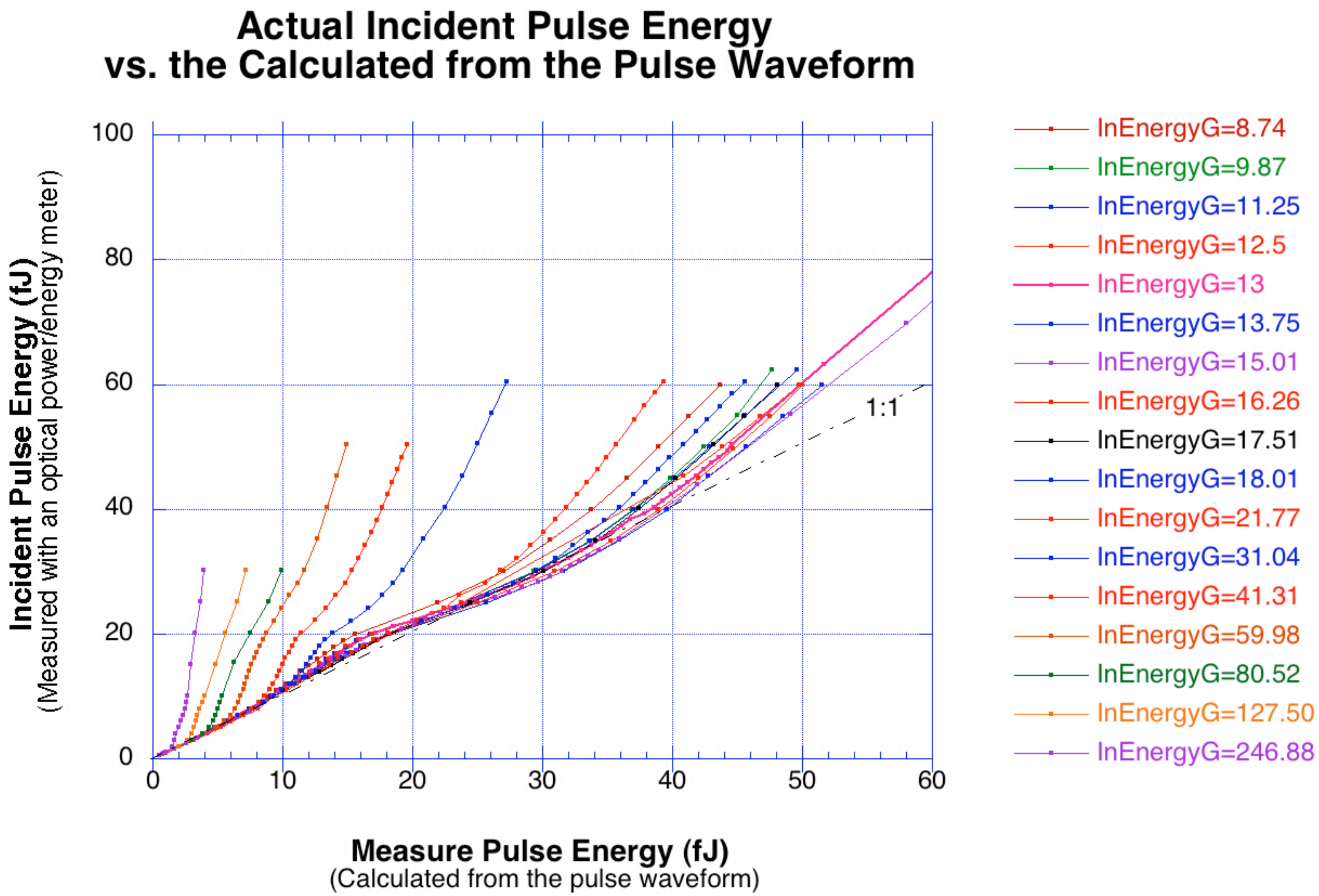


- Saturation can cause a significant reduction in the measured pulse energy;
- A polynomial fit may be used to estimate the actual incident pulse energy from the measured pulse energy.

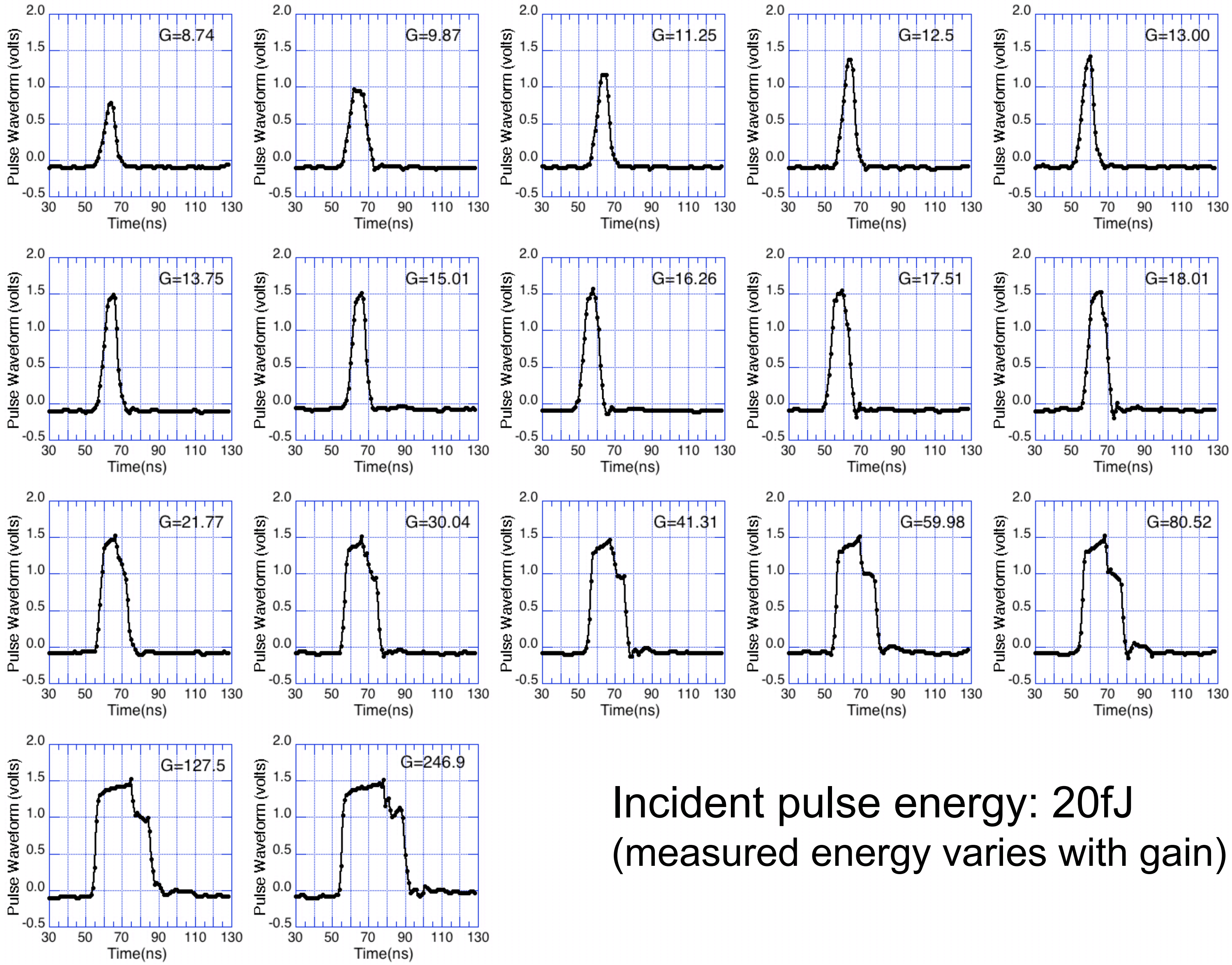
Time Walk vs. Measured Pulse Energy for various gain values



Actual Pulse Energy vs. Measured Pulse Energy for various gain values



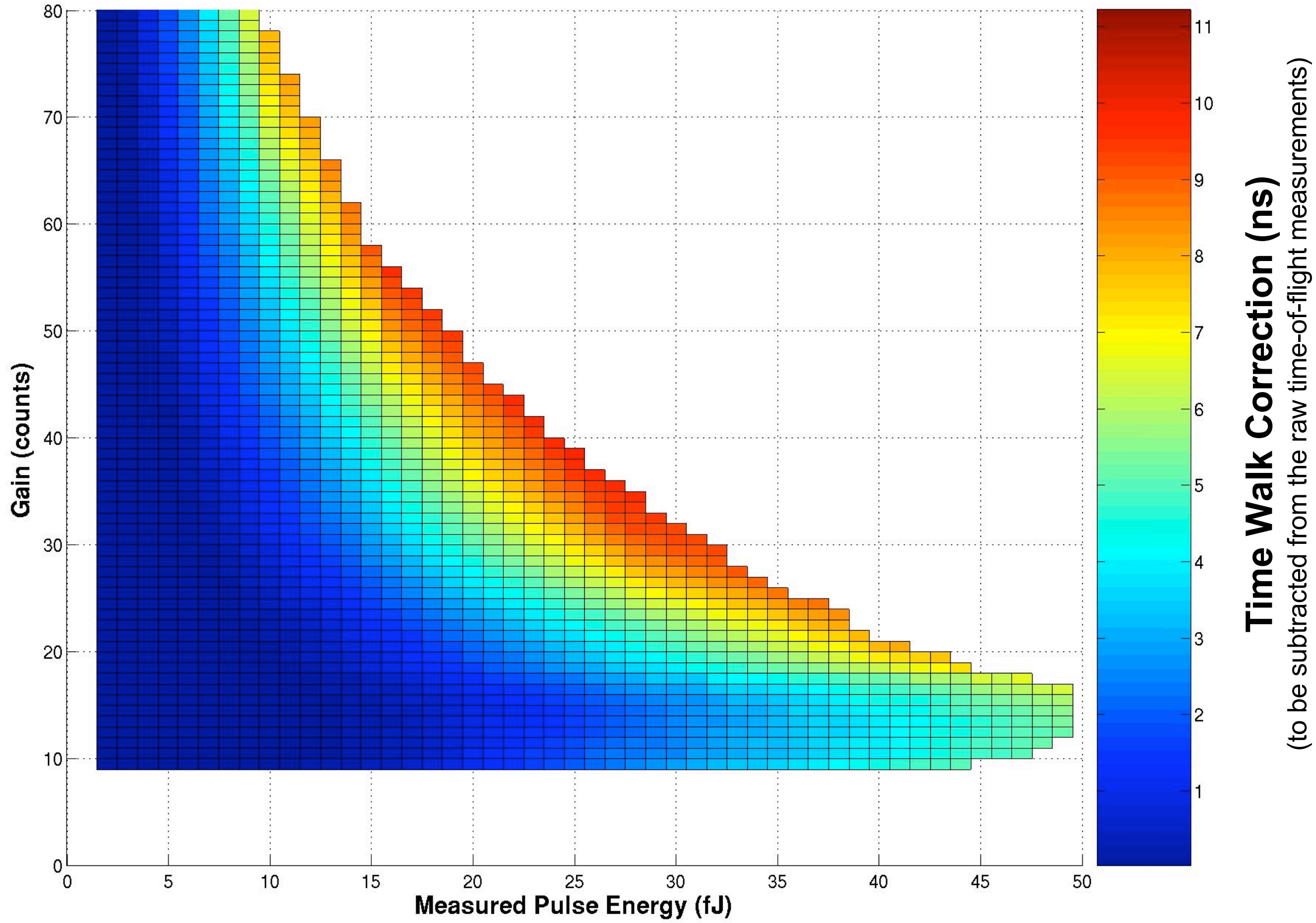
Sample Saturated Pulse Waveforms at Various Gain



Incident pulse energy: 20fJ
(measured energy varies with gain)

Time Walk Correction for Gain<80

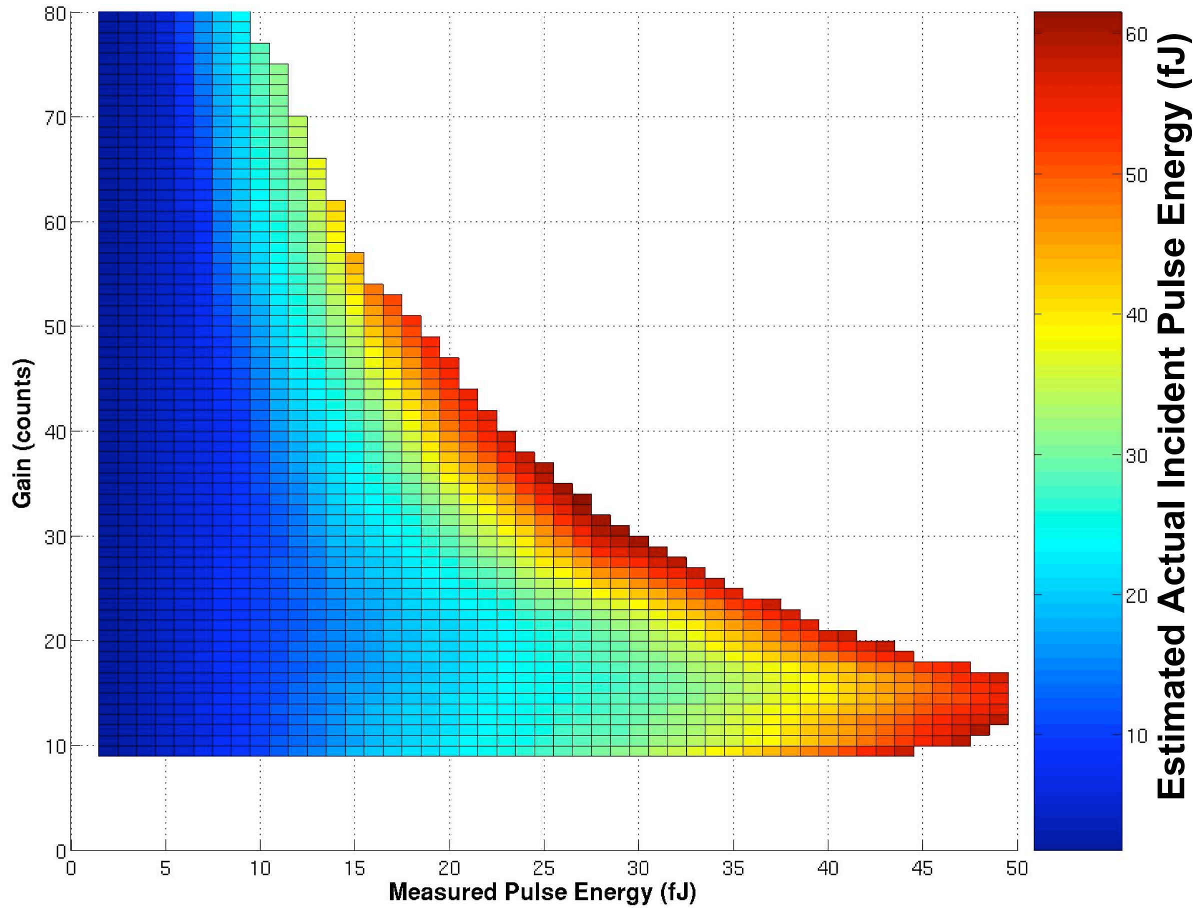
- a look up table obtained by fitting a 3D surface to the lab measurement data



The look up table may be extended to G≥80 via an improved 3D surface fit to the test data.

Actual Incident Pulse Energy Estimation from the Measured Pulse Energ for Gain<80

- a look up table obtained by fitting a 3D surface to the lab measurement data



The look up table may be extended to G≥80 via an improved 3D surface fit to the test data.

Recommended Saturation Correction Algorithm and Procedure

- Identify saturated pulse waveforms
  - Peak pulse amplitude >220 for more than 2ns (“two gates) at Gain≥13

  Or

  - Gain <13
- For pulse energy <45fJ (slight to medium saturated):
  - Use the look-up tables for time walk and pulse energy correction
- For pulse energy ≥ 45fJ & Gain=13 (severely saturated):
  - Use the linear fit function for time walk correction
  - Develop a polynomial for the pulse energy correction
- Others:
  - Put aside and wait for more lab tests and algorithm development.

Task 3 - Alternative Range for Saturated Returns: Leading-edge Timing

Leaders: J. DiMarzio and D. Harding

Primary Focus: Inland water saturated returns with > 40 fJ received pulse energy

Approach: Fit function to leading-edge of transmit pulse and received echo prior to saturation in order to determine range for severely saturated returns where Task 2 calibration approach may not preserve range precision to flat surfaces

Status: Coding is complete to fit the waveform leading edge with an exponential function. The code is being tested.

Remaining Work: Look at the test results vs. "ground truth" in areas where surface elevation is known. One possible location is in the Florida Everglades where returns are very saturated. Also, of course Uyuni. Possibly try other functions (e.g. polynomial). Coding was done so that fit function is easily changed.

Schedule: Complete study by 12/1/05

Task 4 - Received Waveform Alternate Gaussian Fitting

Leaders: D. Hancock and D. Harding

Primary Focus: Multi-Gaussian peak fitting to complex land waveforms

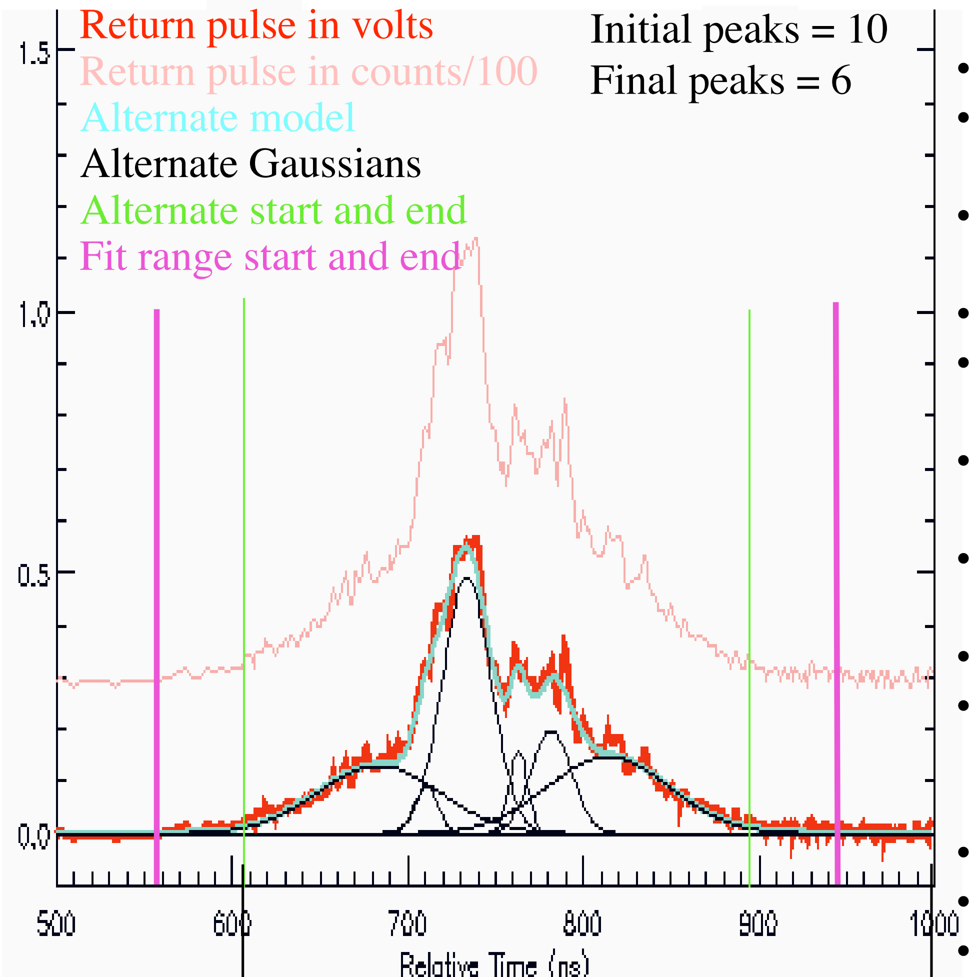
Approach: Revise alternate GSAS code to match Waveform ATBD
Test sensitivities of input parameters using multiple acctest runs on a test segment of complex land waveforms
Apply GSAS code to synthetic waveforms (analytic and simulated from high-res DEMs) in order to compare fit results to known distributions in order to assess accuracy

Status: Code modifications completed, preferred set of input parameters identified, and implemented in GSAS 5.0

Remaining Work: Assess how to best report quality of fit metric (relative or absolute)
Assess if above-atmosphere or within-waveform noise should be used
Apply fitting to synthetic waveforms to assess accuracy
Document fitting method and accuracy of results

Schedule: Complete by 12/05 for inclusion in GSAS 5.1

GSAS 5.0 Alternate Waveform Fitting



4 nsec averaging lowers noise standard dev.

1 nsec sampling (no compression)

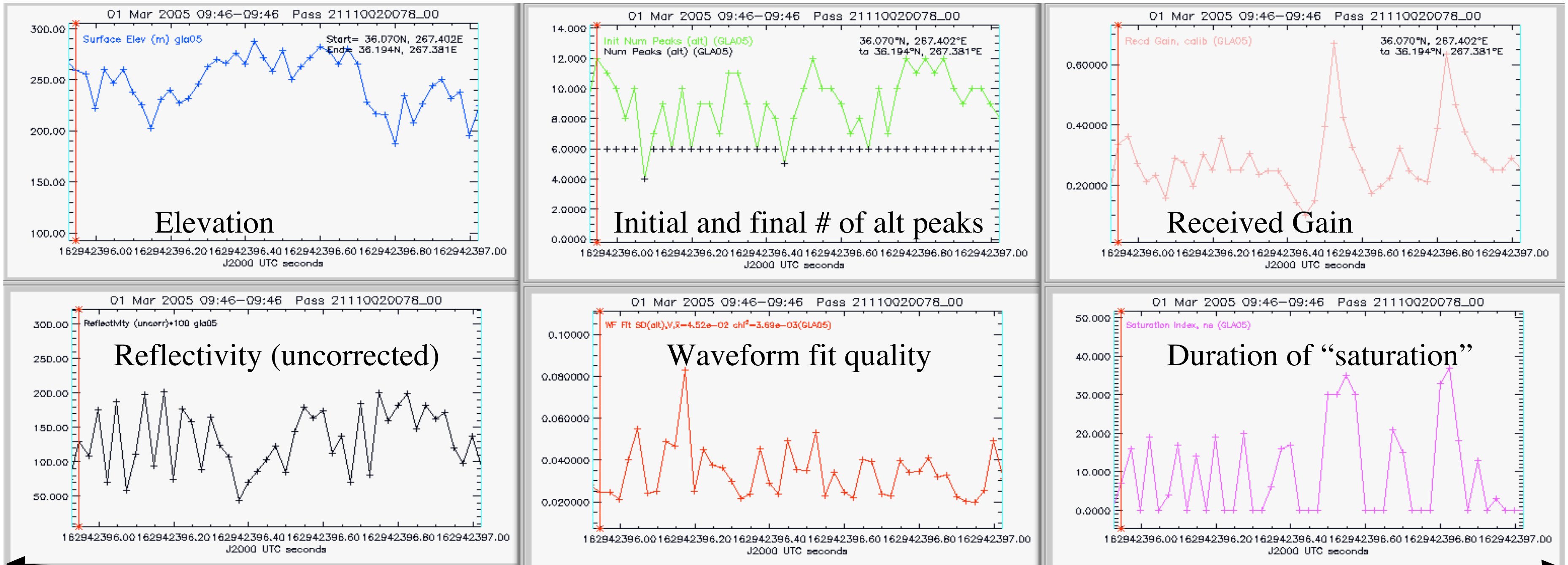
Land waveform compression starting with L2b

Fitting Parameters and Constraints

- smooth waveform using 16 nsec filter width
- constrain distance btw peak centers to be no less than 15 nanoseconds (2.25 m)
- define initial peak locations using 2nd derivative (peaks bounded by waveform inflections)
- constrain peak centers to be btw alternate start and end
- constrain Gaussian fit base-level to be equal to background noise level
- define fit range to be 50 nanosec before alternate start to 50 nanosec after alternate end
- compute initial set of Gaussian distributions using non-smoothed, peak-normalized waveform
- retain last Gaussian distribution + 5 largest by area
- use wt_sgm = 0.03 in least squares iteration adjustment of peak amplitude, width & location (controls how much peaks will broaden)
- allow Gaussian distributions to extend beyond fit range
- allow peak amplitudes to go to zero during iteration
- compute WF Fit SDEV on peak-normalized waveforms within fit range, and account for land compression
- iterate until WF Fit SDEV converges (12 max iterations)

- **SOLUTION IS ONE OF MANY NON-UNIQUE FITS**

41 sec South-Central U.S. L3b Profile Used for Evaluation of Fit Tests



Acceptance Test Results in /SCF/product_sets/acctest:
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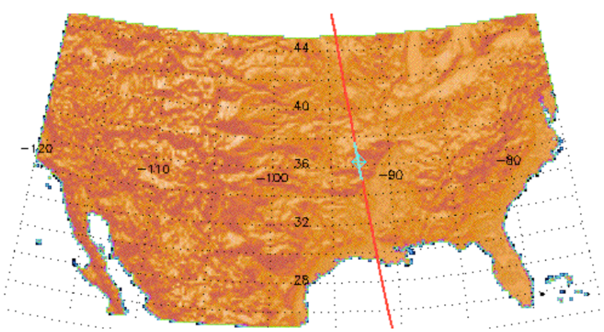
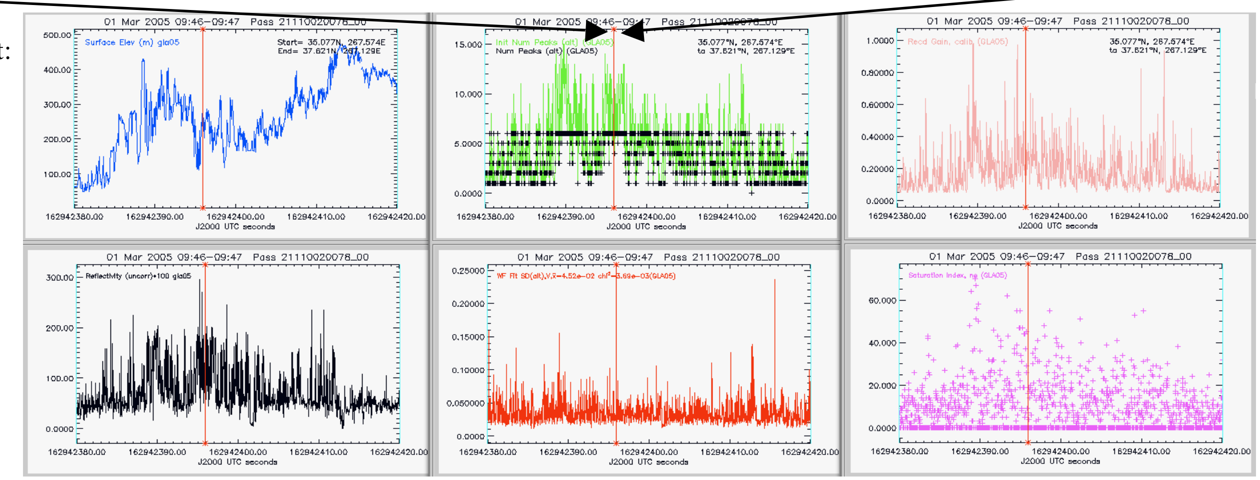
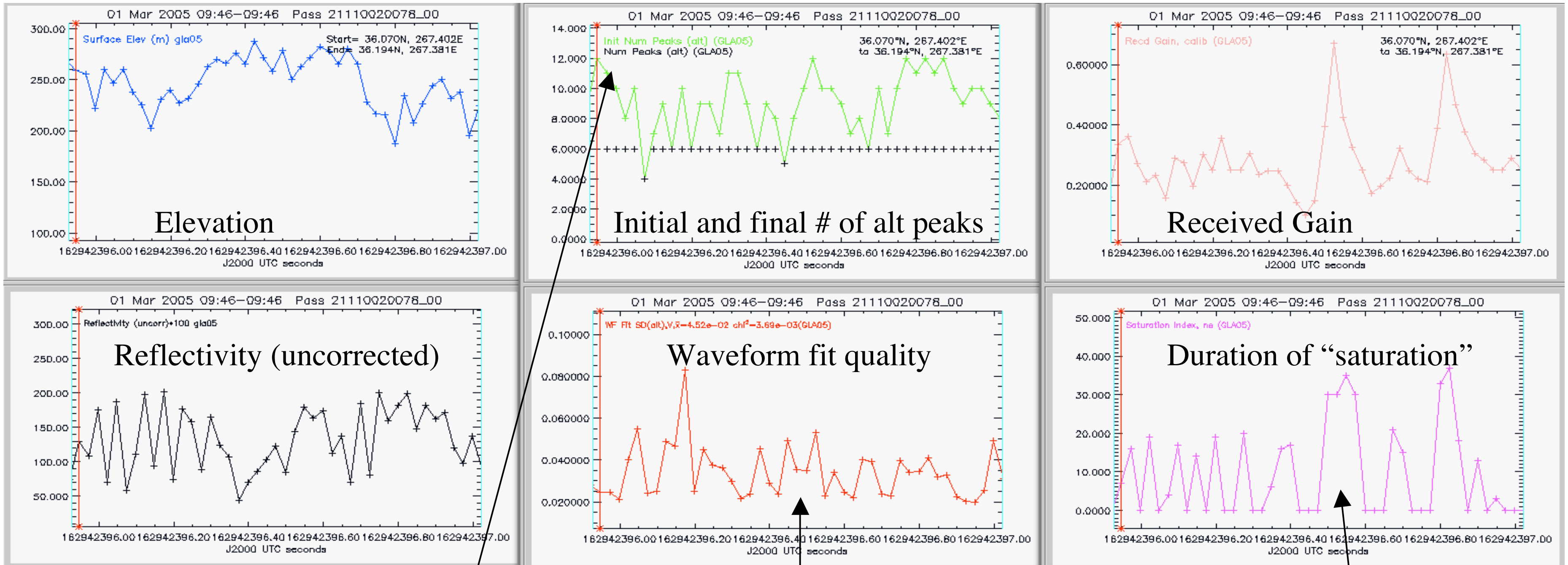
GLA05_920_2111_002_0078_4_03_0001.DAT_03





41 sec South-Central U.S. L3b Profile Used for Evaluation of Fit Tests



Increased smoothing and minimum peak distance reduced initial number of peaks to more reasonable level (prior versions often had > 40).
If init > 6, last peak + 5 largest retained.
If init ≤ 6, all peaks retained.
Amplitude can go to 0 during iteration.

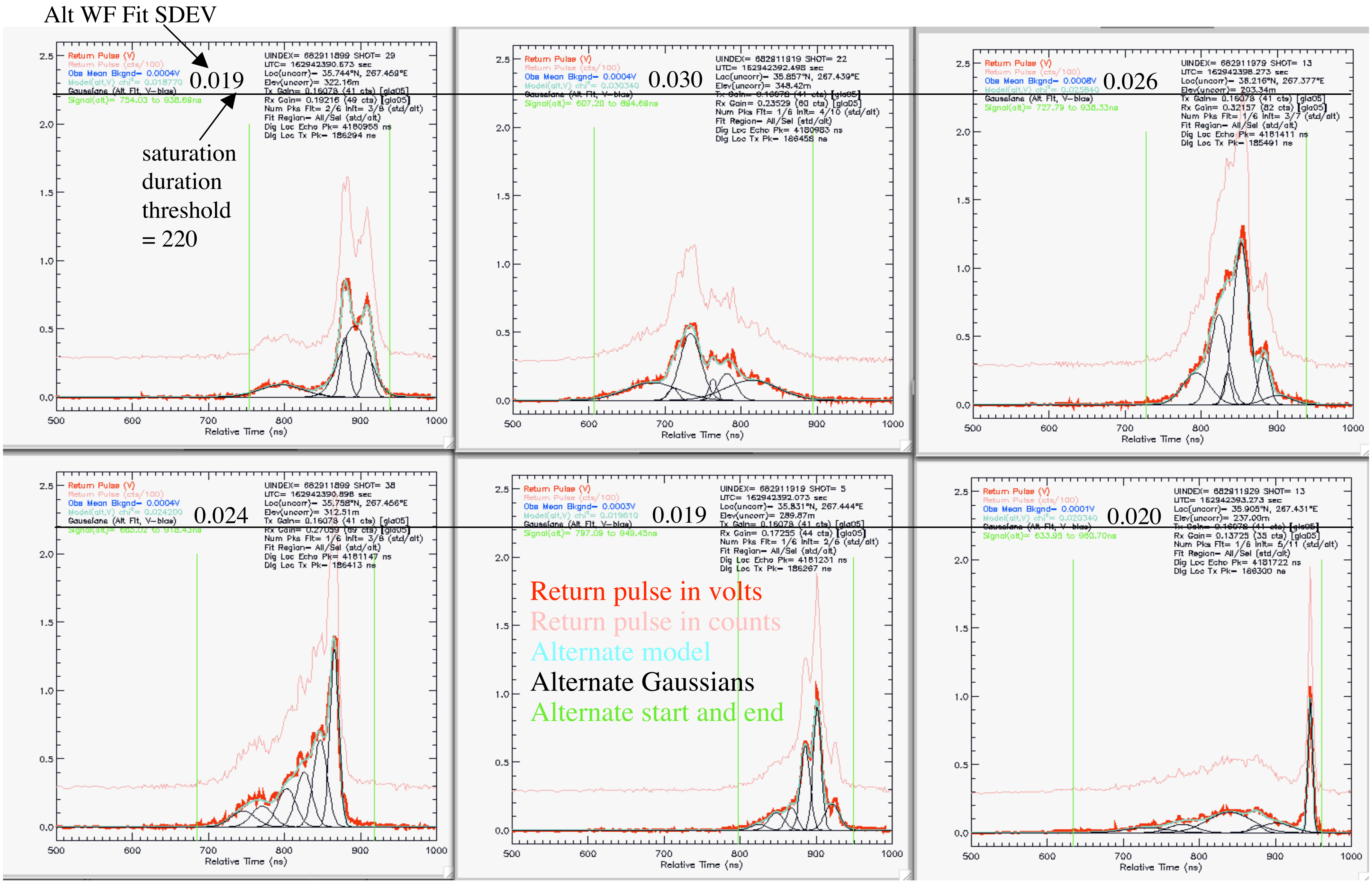
WF Fit SDEV(alt) = measure of fit quality computed as **root mean square** of the differences between the received waveform and alternate model, each with peak amplitude normalized to 1 (a relative difference).

Saturation Index = measure, in nanoseconds, of saturation duration when amplitude is above 220 digitizer counts (threshold may be a function of gain in future releases).

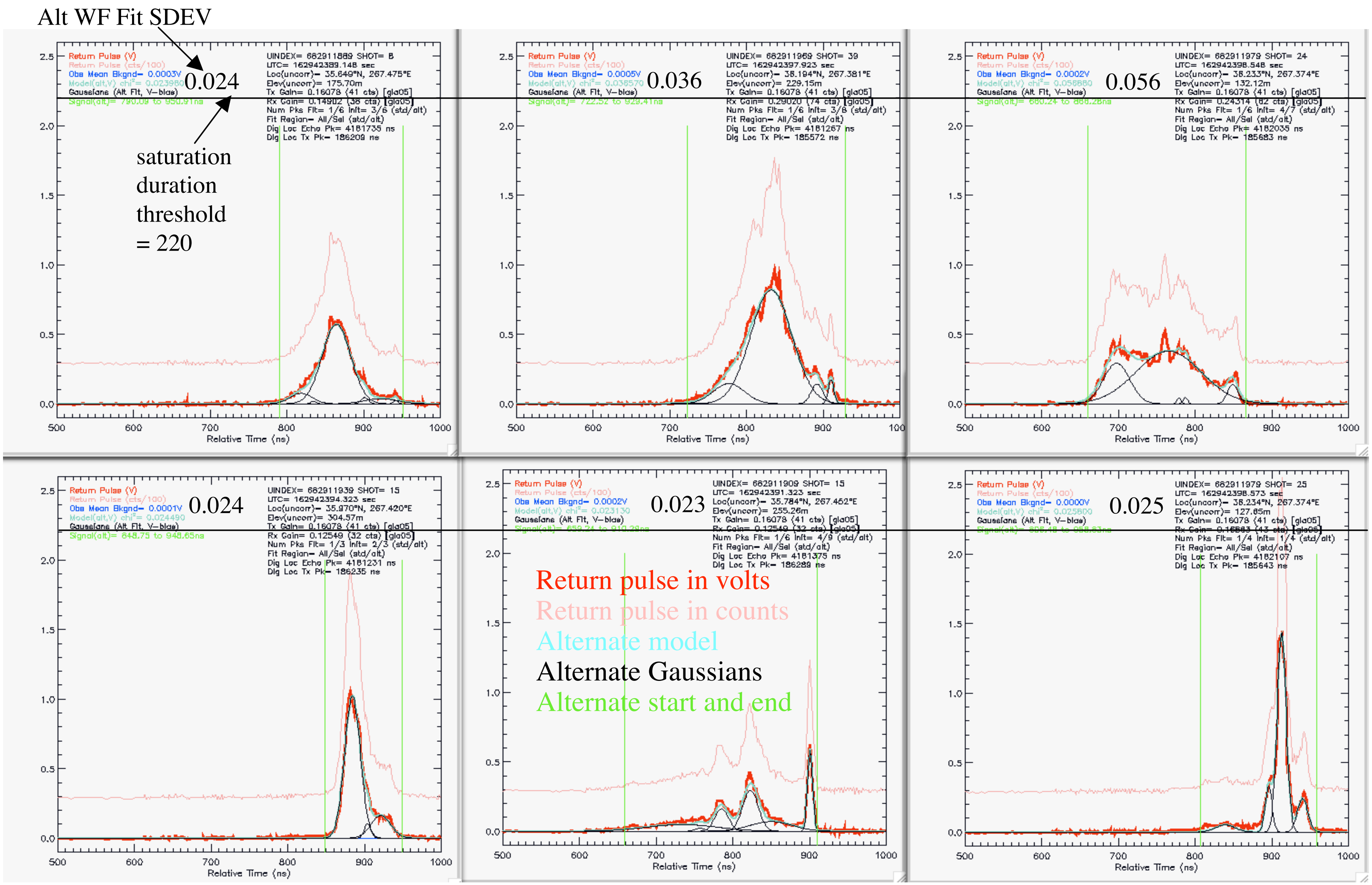
$$\text{WF Fit SDEV (alt)} = \sqrt{\frac{1}{N\text{-}1}\sum_{i=1}^{N}(x_i - m_i)^2}$$

x_i = received amplitude, normalized by received peak amplitude, for waveform gate i
m_i = model amplitude, normalized by model peak amplitude, for waveform gate i
N = waveform gates used to define model fit

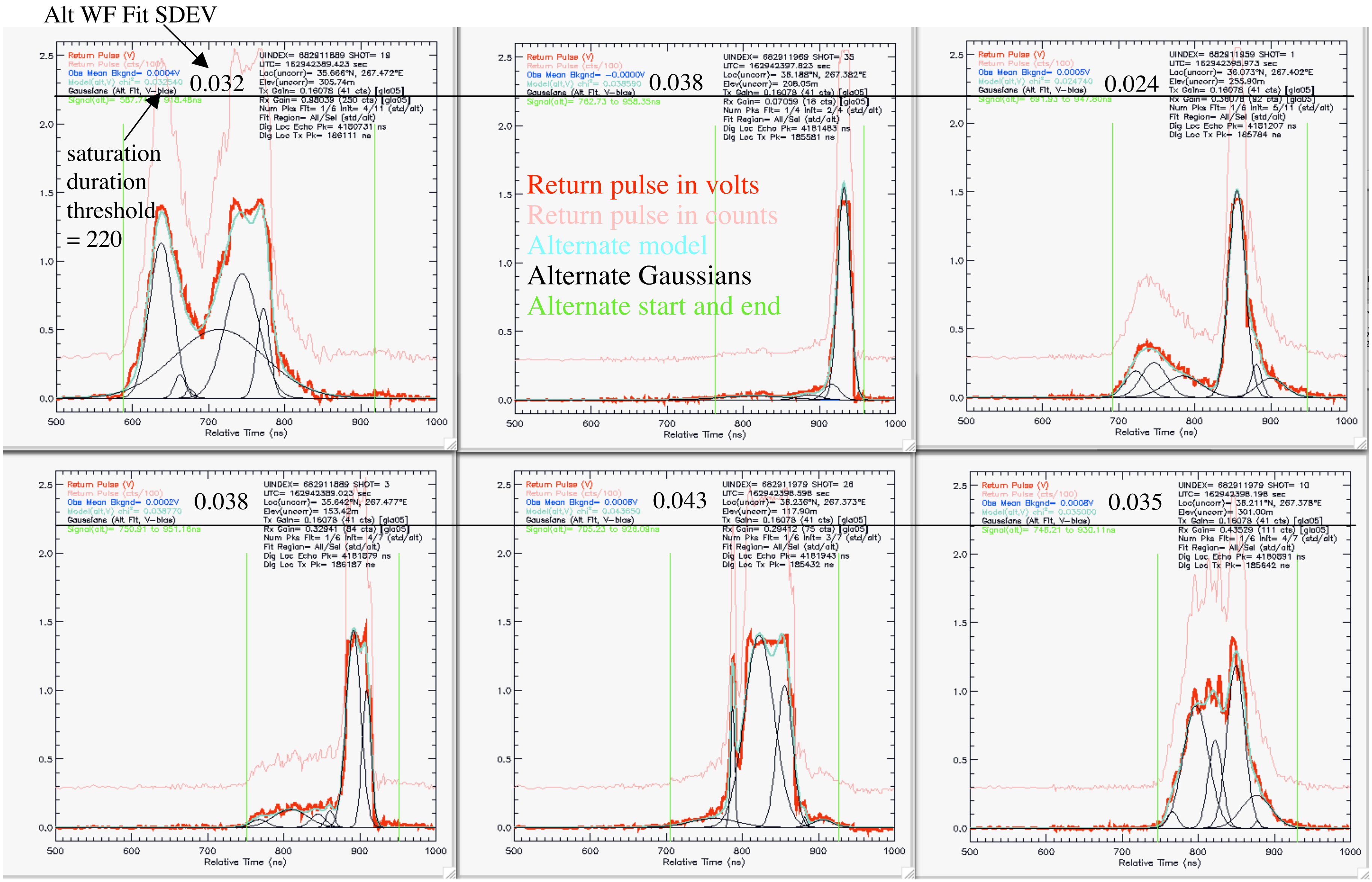
Examples of good fits to complex waveforms



Examples of fits that identify last peak that may be ground

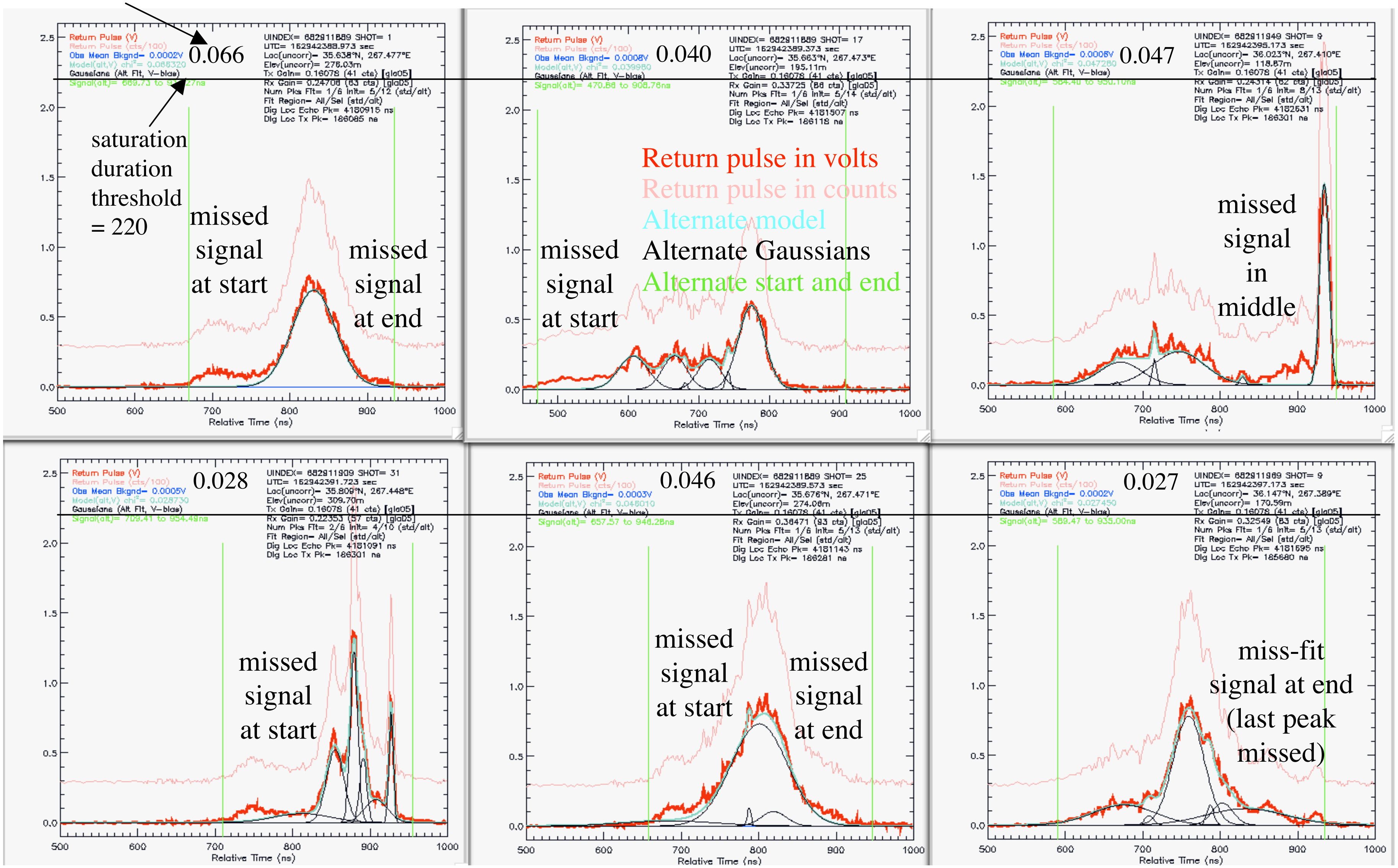


Examples of good fits to saturated waveforms

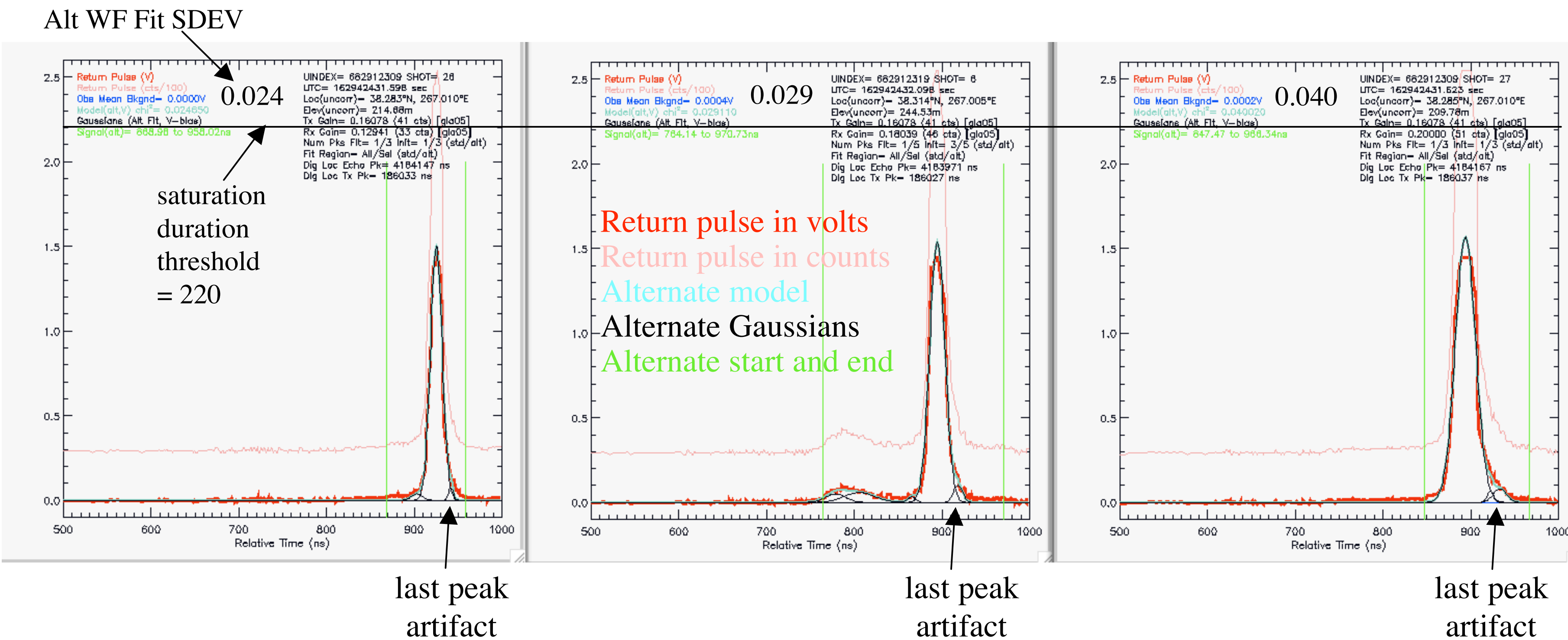


Examples of poor fits to complex waveforms

Errors are missed signal, not inclusion of peaks where no signal is present



Examples of Saturated Waveforms with Last Peak Artifacts



Recommendation for alternate fit users who want to identify the last valid peak:

Use the 6 Gaussian fit position-width-amplitude parameters to assess if the last peak is a valid peak.

If last peak (or peaks - note right hand example has two artifact peaks at the end) has a “low” amplitude and “closely” follows a “narrow” peak and its amplitude is a “small” fraction of that larger preceding peak, then ignore that last peak(s).

Used in initial test: Low: < 0.2 v; Close: 40 ns(1 artifact), 60 ns (2 artifacts); Narrow: sigma < 13 ns ; Small: < 0.08

Recommendation for alternate fit users who want to assess if last valid peak might be “ground”

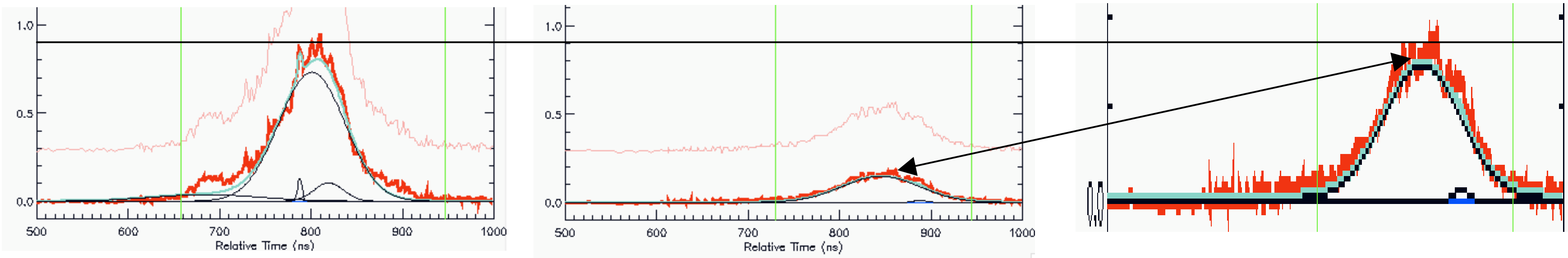
(e.g., a ground, snow surface or water return beneath vegetation):

Last valid peak should be “narrow” and not “significantly” overlap with other peaks.

Used in initial test: Narrow: sigma < 10 ns; Significant: last valid peak ampl. > 1.5 * ampl. sum of other peaks @ last valid

Interpretation of WF Fit SDEV

WF Fit SDEV = 0.046 WF Fit SDEV = 0.067



When viewing waveforms plotted with volts scaled equally, a waveform fit with a higher WF Fit SDEV value can visually appear to be a better fit because the value is computed using peak-normalized received and model waveforms. Thus the value is a relative measure of quality; multiplied by 100 it is the RMS error per nanosecond as a percent of the peak amplitude. Adjusting peak amplitudes to be equal, the waveform fit with the higher WF Fit SDEV value is observed to be less good in a relative sense.

Recommendation for alternate fit users who want an absolute measure of fit quality

Multiply WF Fit SDEV by received waveform peak amplitude to derive RMS error per nanosecond in volts:

0.046 * 0.9 volts = 0.04 volts 0.067 * 0.18 volts = 0.01 volts

The received waveform peak amplitude is provided in GLA05.i_maxRecAmp. Alternatively, a very close estimate of the peak amplitude can be obtained from i_maxSmAmp available in GLA05, 06, 12, 13, 14 and 15 (the smoothing applied is that using the standard filter width of 8 nsec which only slightly reduces the peak amplitude).

Either as a % or volts error, this is a measure of fit quality averaged over the entire fit range.

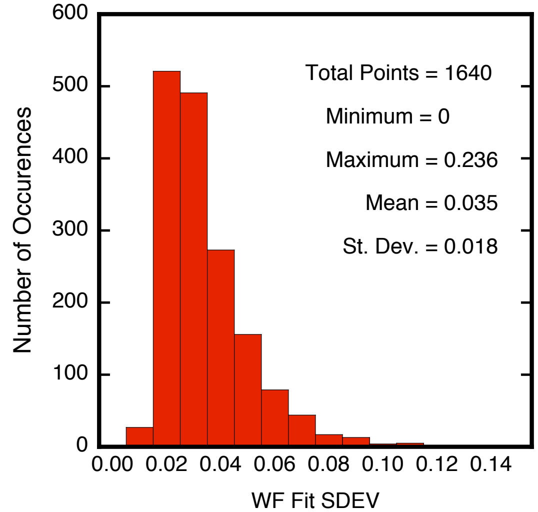
It is not indicative of variable fit quality, with no indication if parts of the waveform are more or less misfit.

A measure of areas of missed signal would be a useful product addition.

Relative and Absolute WF Fit SDEV Characteristics

(for 1640 land waveforms)

Relative WF Fit SDEV (%) * Peak Amplitude (smoothed) = Absolute WF Fit SDEV (v)



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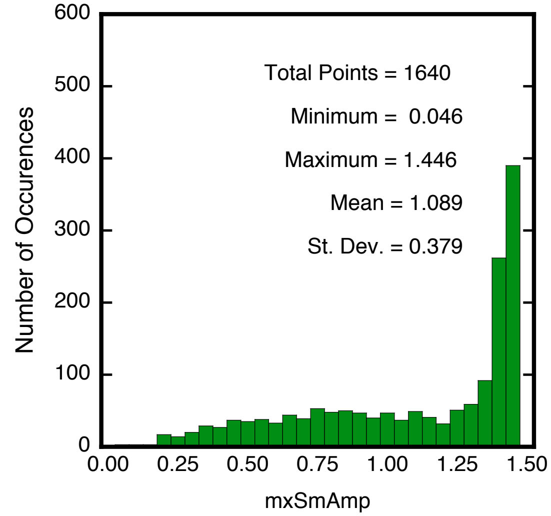

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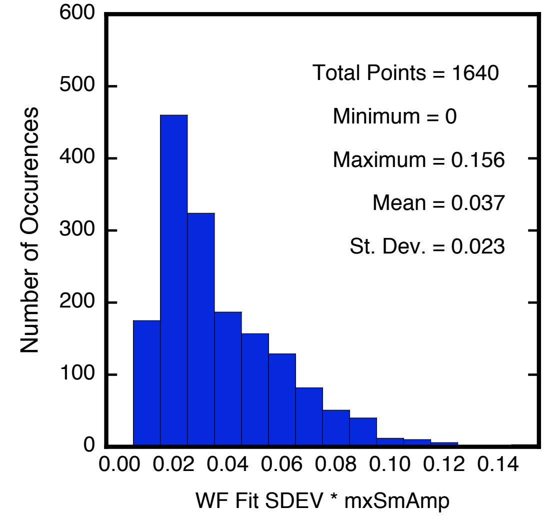
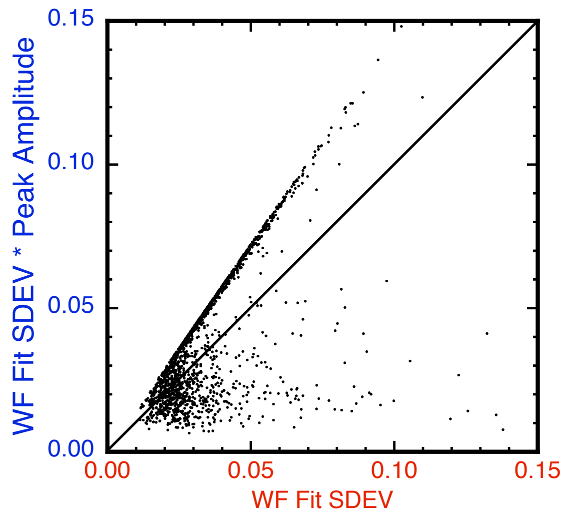
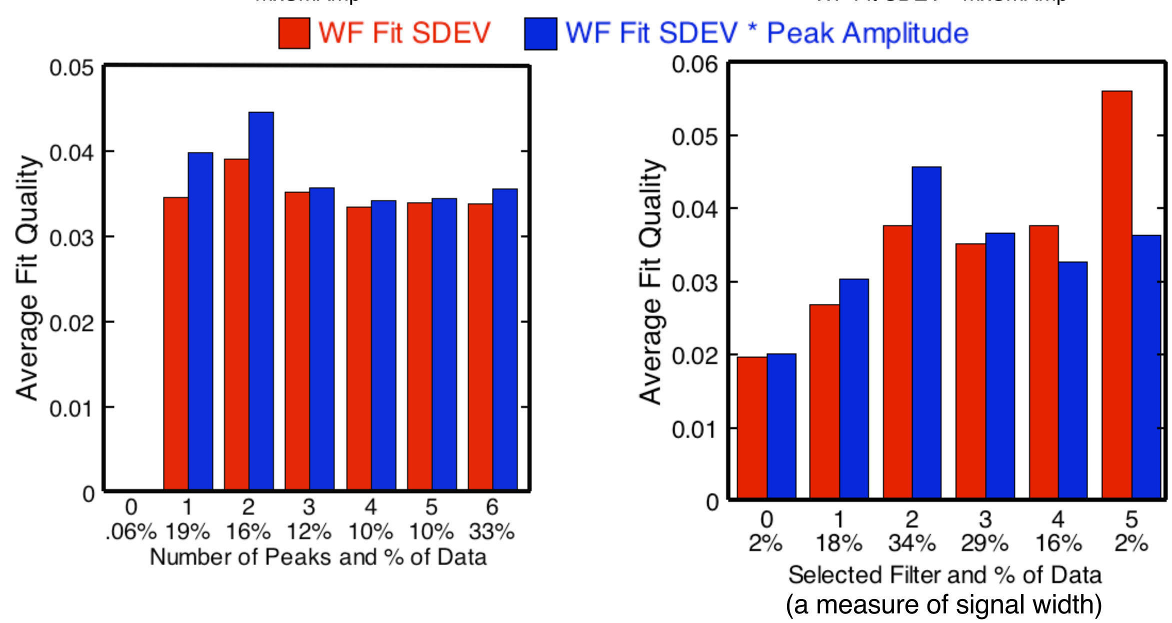
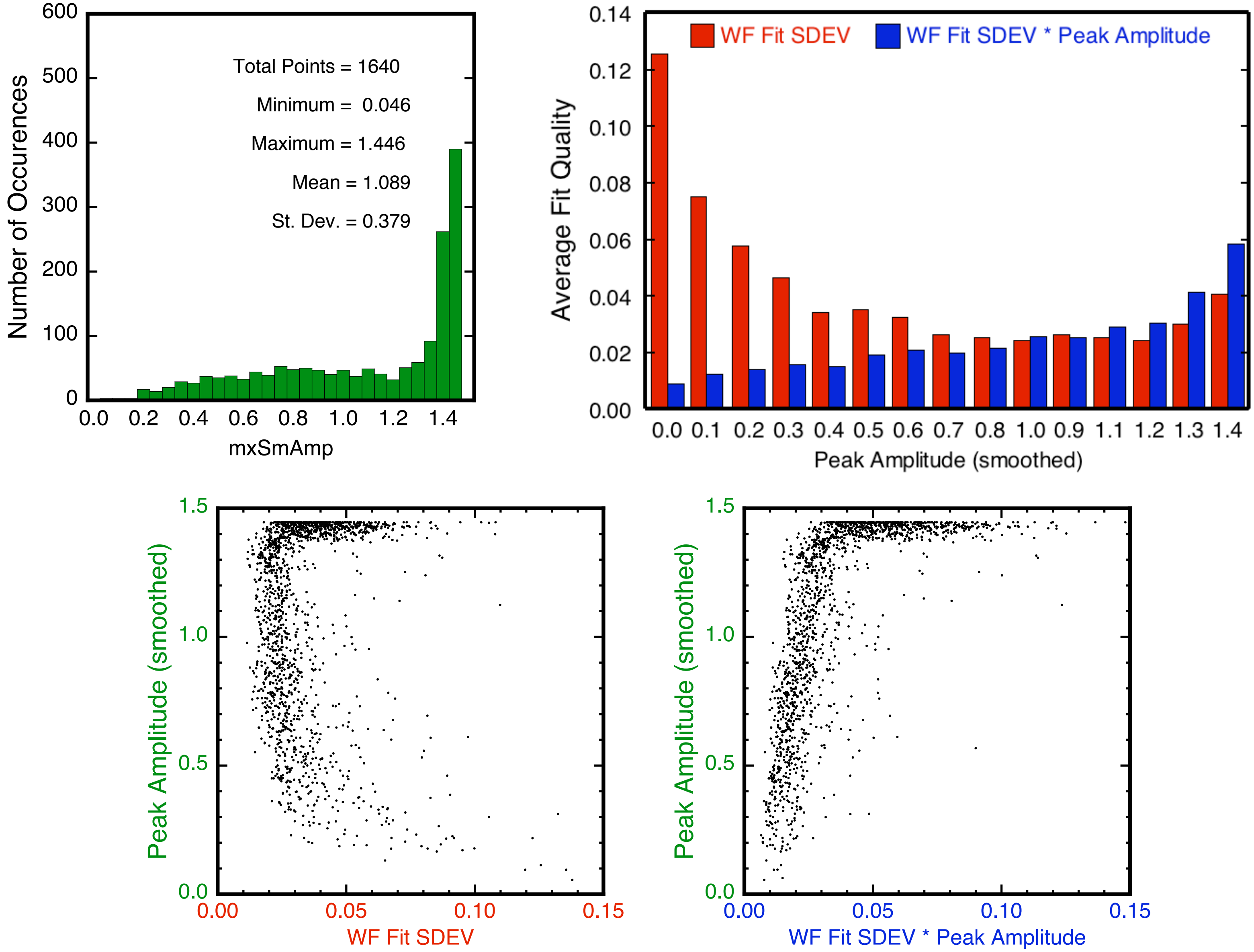


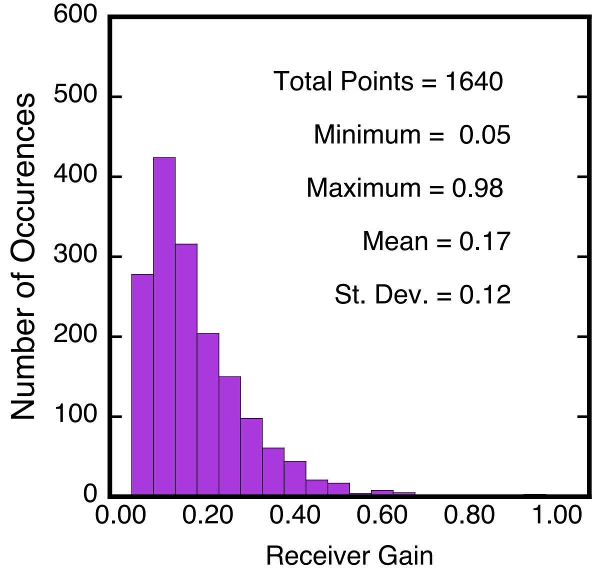


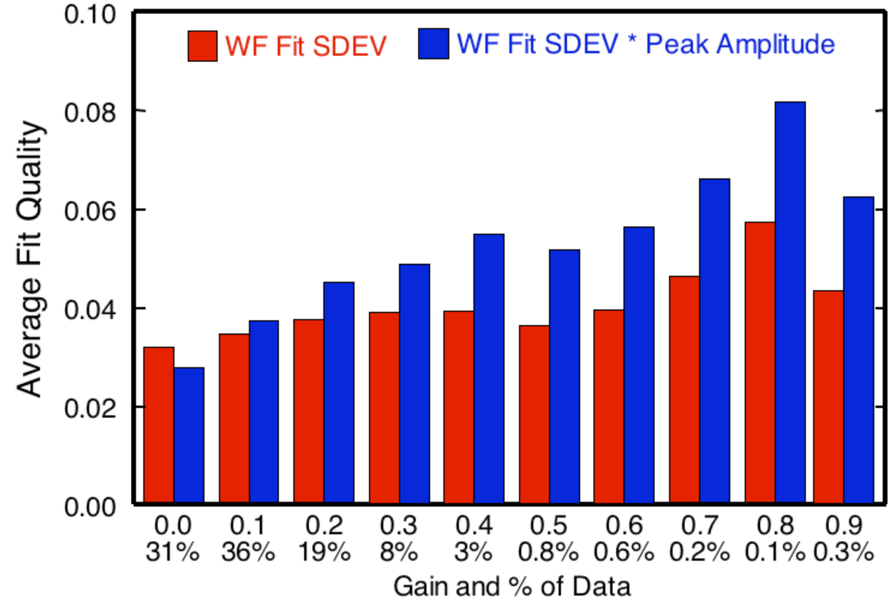


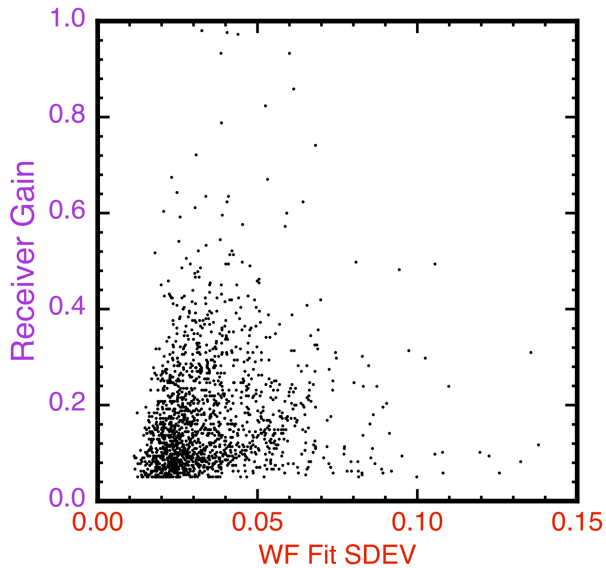
Relative and Absolute WF Fit SDEV vs. Peak Amplitude
(for 1640 land waveforms)

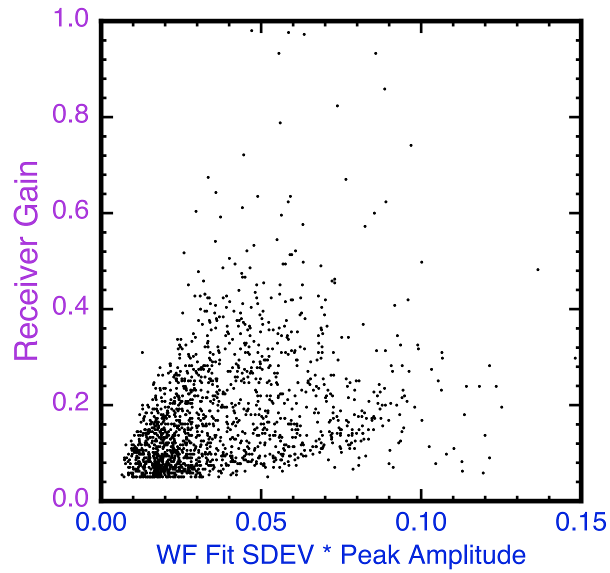


Relative and Absolute WF Fit SDEV vs. Receiver Gain
(for 1640 land waveforms)









Conversion of WF Fit SDEV to Units of Optical Power

From Xiaoli Sun, Conversion of the GLAS Altimeter Digitizer Output to the Received Optical Signal Power and Energy - Rev 4, dated 11-22-02.

WF Fit SDEV, after converting to volts by multiplying by the waveform peak amplitude, is an absolute measure of the model misfit with respect to the GLAS detector output.

The model misfit with respect to the optical power input, in watts, to the GLAS receiver can be obtained by scaling WF Fit SDEV in volts using the receiver gain according to the following:

$$P_{SDEV} = v_{SDEV} \;/\; (\eta_c * \eta_{optical} * R_{\det} * G_{VGA} * \alpha_{cal}) = v_{SDEV} \;/\; (G_{VGA} * 1.706e7)$$

where

v_{SDEV} is the WF Fit SDEV in volts

$\eta_c = 0.923$ is the circuit throughput from the detector to the digitizer

$\eta_{optical} = 0.670$ is the receiver optics transmission for the received echo

$R_{\det} = 2.28e7$ Volts/Watts is the detector responsivity

G_{VGA} = GLA05.i_gval_rcv / $(2^8 - 1)$ is the normalized gain of the variable gain amplifier

$\alpha_{cal} = 1.21$ is the calibration coefficient from pre-launch system level test data

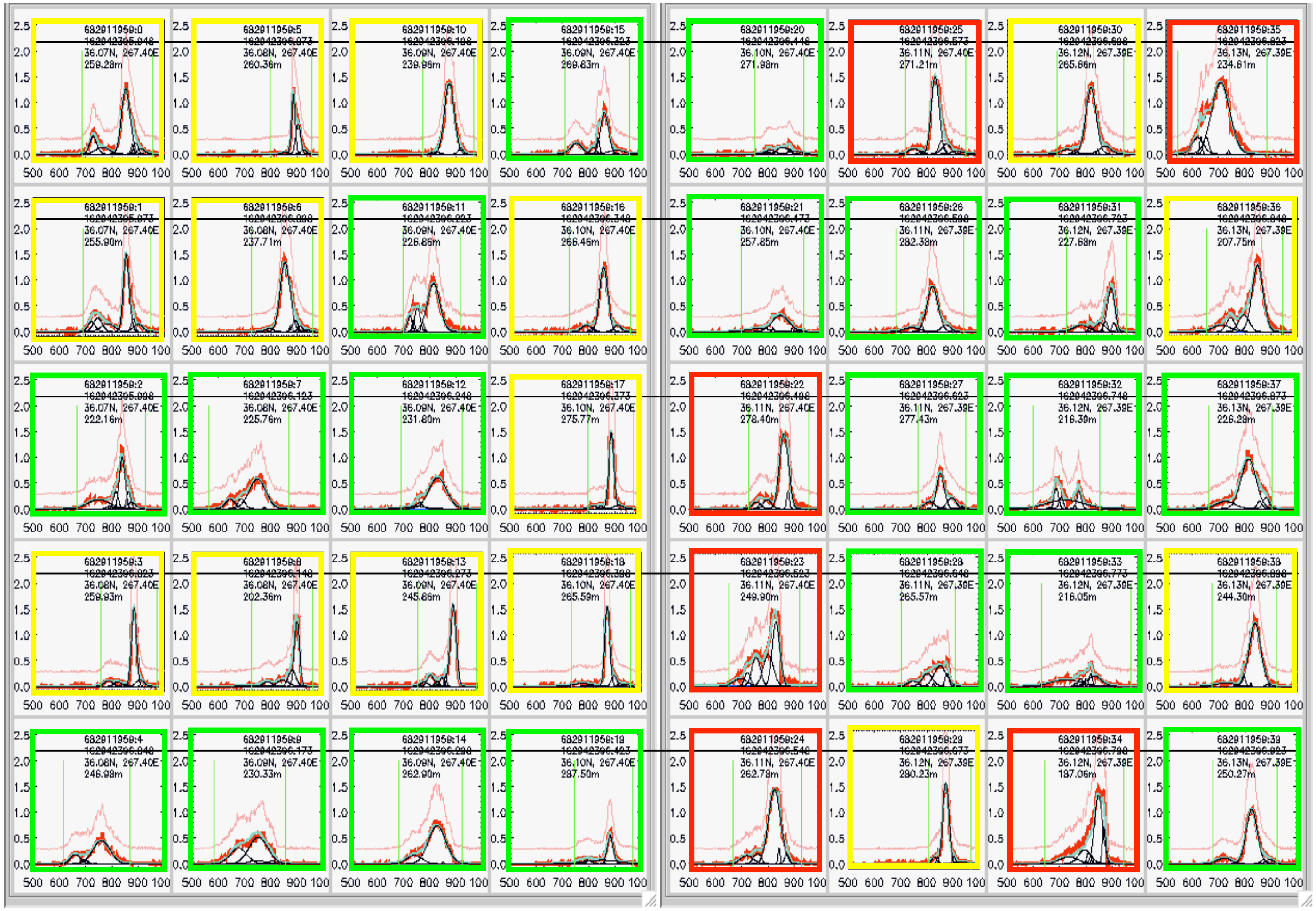
P_{SDEV} is WF Fit SDEV in Watts.

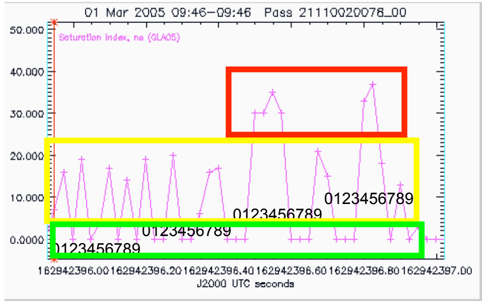
This converted value will not be an accurate measure of misfit with respect to optical power for saturated waveforms, which are distorted and broadened when the input optical power exceeds the linear portion of the GLAS instrument response. Duration of saturation is indicated by the Saturation Index (GLA05.I_satNdx).

Validation of Saturation Duration by Inspection

40 shot waveform sequence

saturation index





Saturation:

significant

moderate

none

Plot Key:

Return pulse in volts

Return pulse in counts

Alternate model

Alternate Gaussians

Alternate start and end

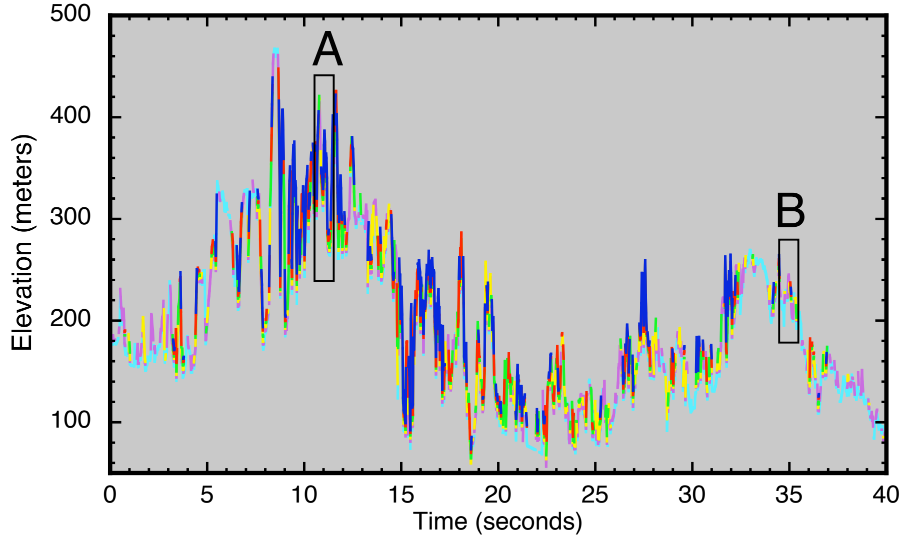
Y - axis maximum = 2.6 Volts and 260 / 100 digitizer counts

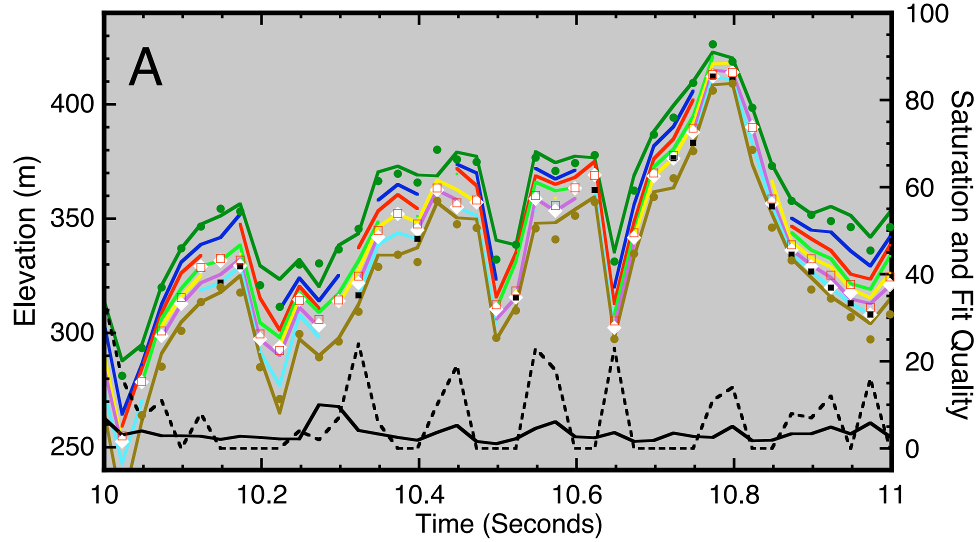
X - axis range = 500 to 1000 nanosec

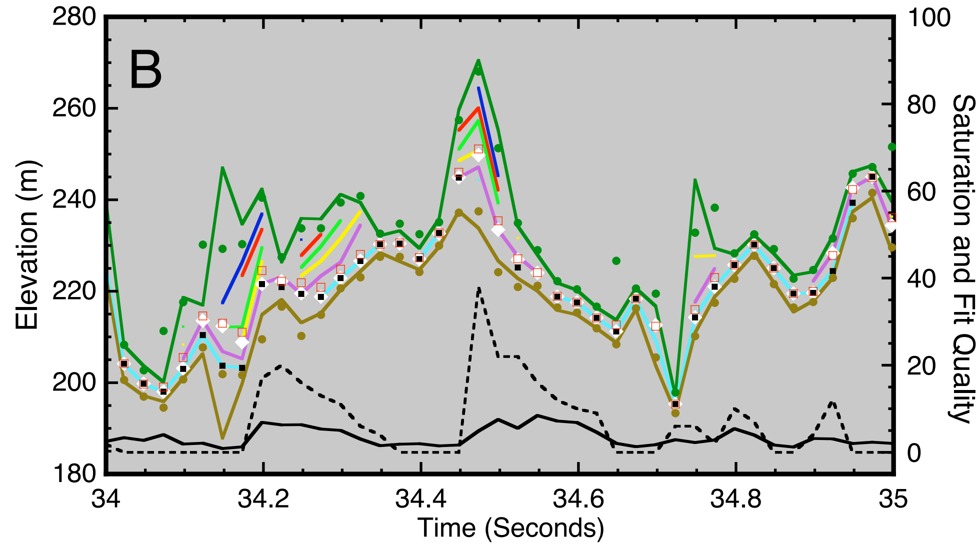
Example of Canopy Height and Structure Derived from GSAS 5.0 Alternate Fitting in Comparison to Previously used Alternate Signal Start, Centroid, and End

Applications of Alternate Waveform Fitting

Vertical Structure of Forest Canopy







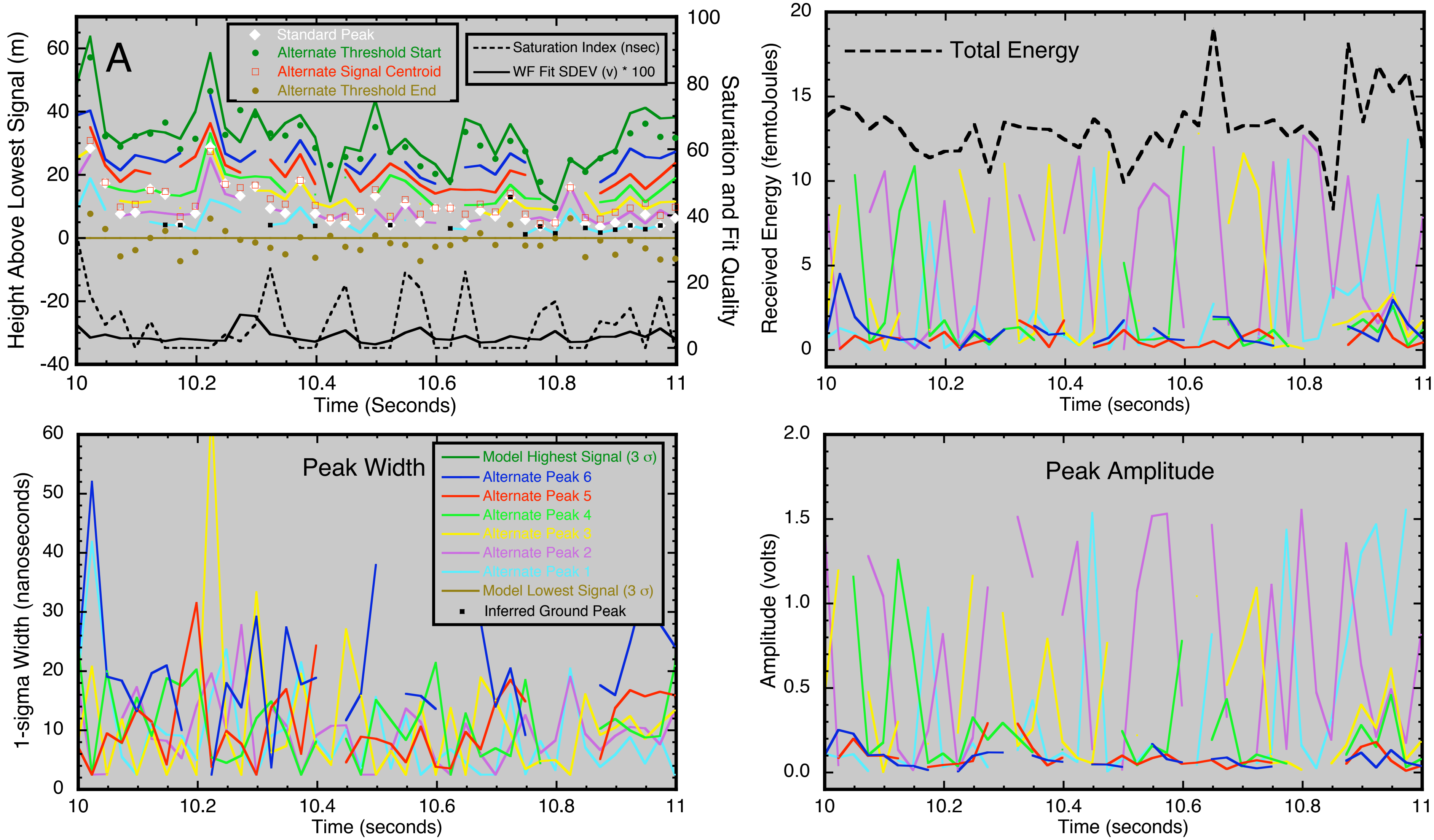
- Model Highest Signal (3 σ)
- Alternate Peak 6
- Alternate Peak 5
- Alternate Peak 4
- Alternate Peak 3
- Alternate Peak 2
- Alternate Peak 1
- Model Lowest Signal (3 σ)
- Inferred Ground Peak

- Standard Peak
- Alternate Threshold Start
- Alternate Signal Centroid
- Alternate Threshold End

- Saturation Index (nsec)
- WF Fit SDEV (v) * 100

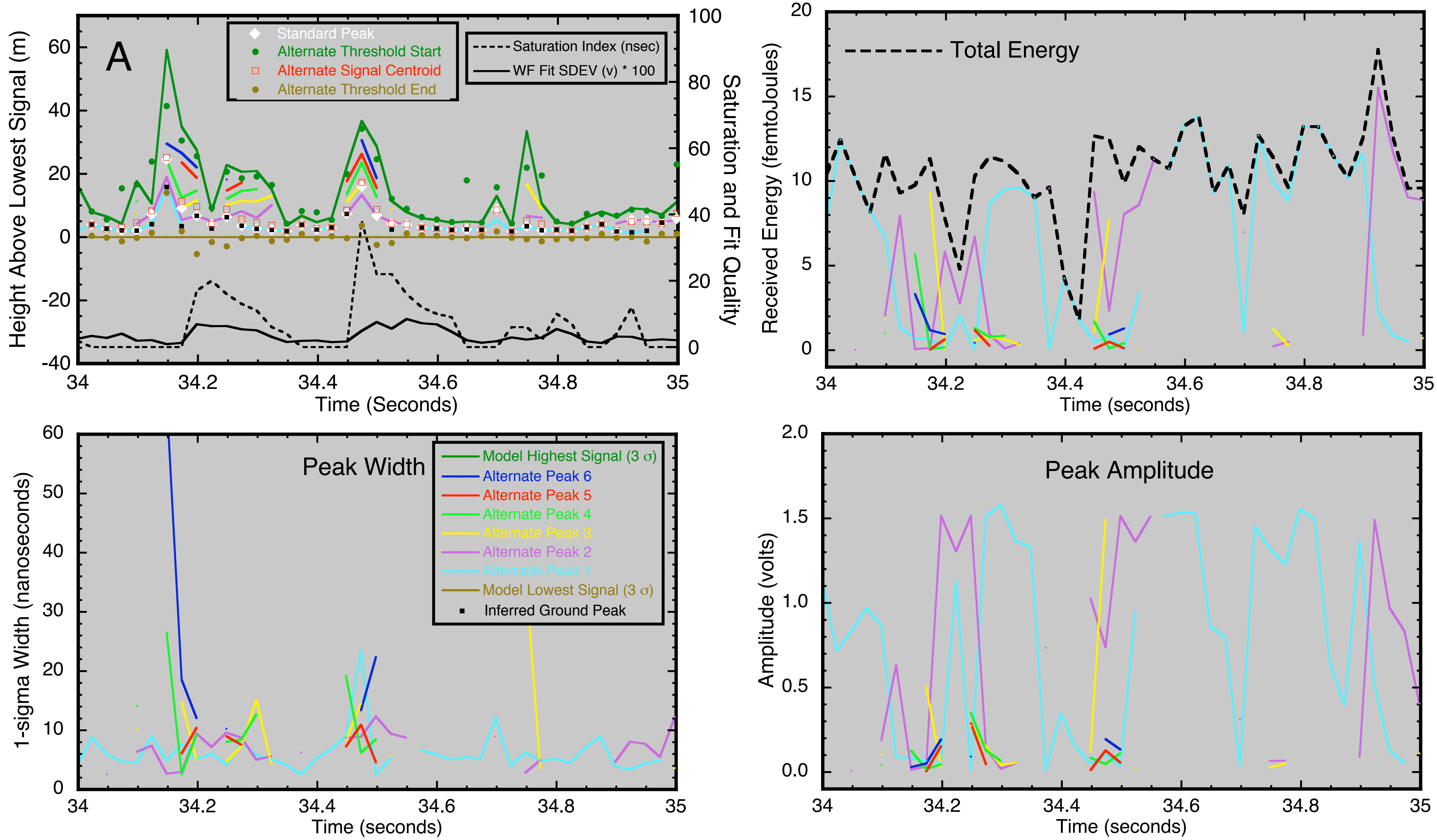
Alternate peaks with amplitude = 0 not plotted. Ground peaks are based solely on the shape of individual waveforms. Along-profile contiguity of ground peaks not yet included as a test. Local slope not yet included in ground peak width criterion.

Vertical Structure of Forest Canopy



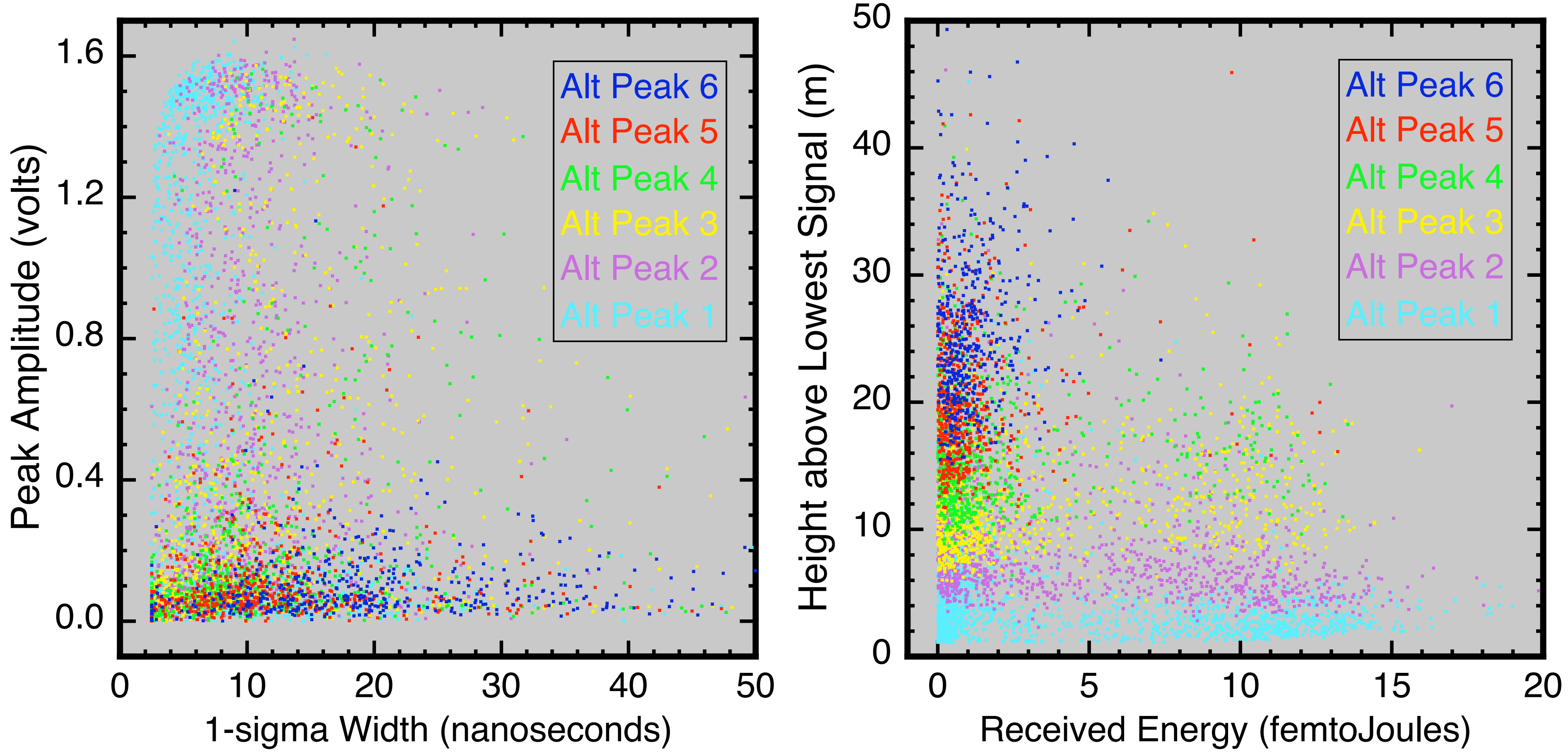
Applications of Alternate Waveform Fitting

Vertical Structure of Forest Canopy



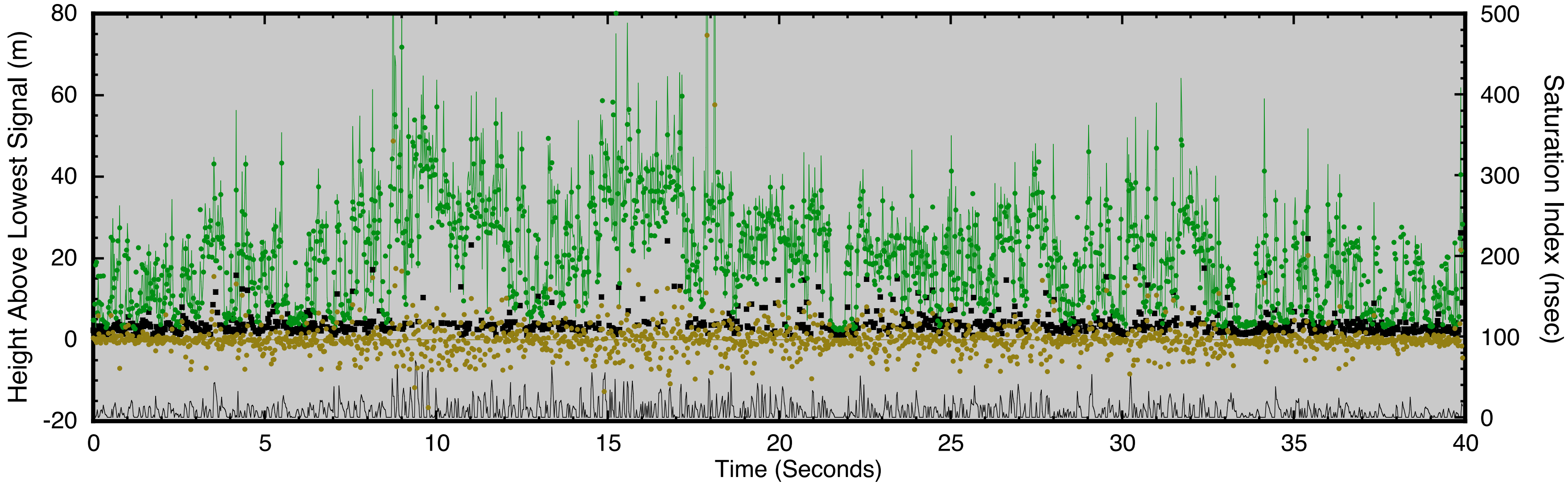
Applications of Alternate Waveform Fitting

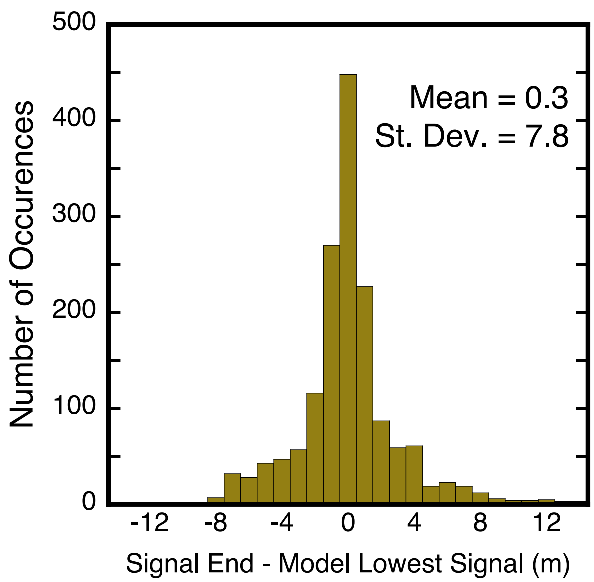
Vertical Structure of Forest Canopy

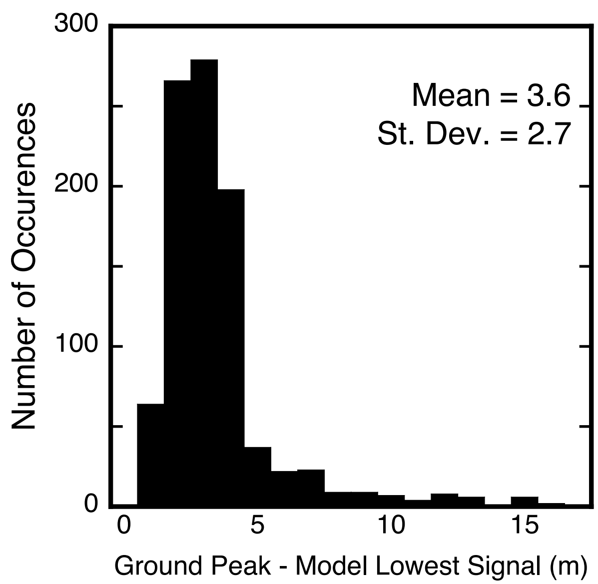


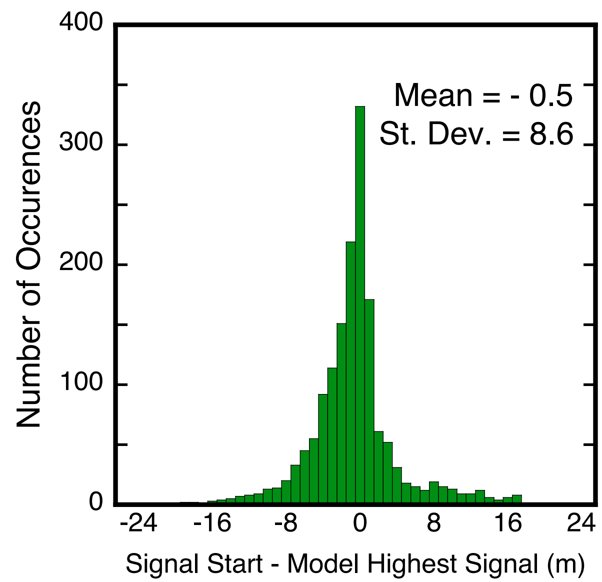
Applications of Alternate Waveform Fitting

Model Lowest and Highest vs. Signal Threshold Start and End

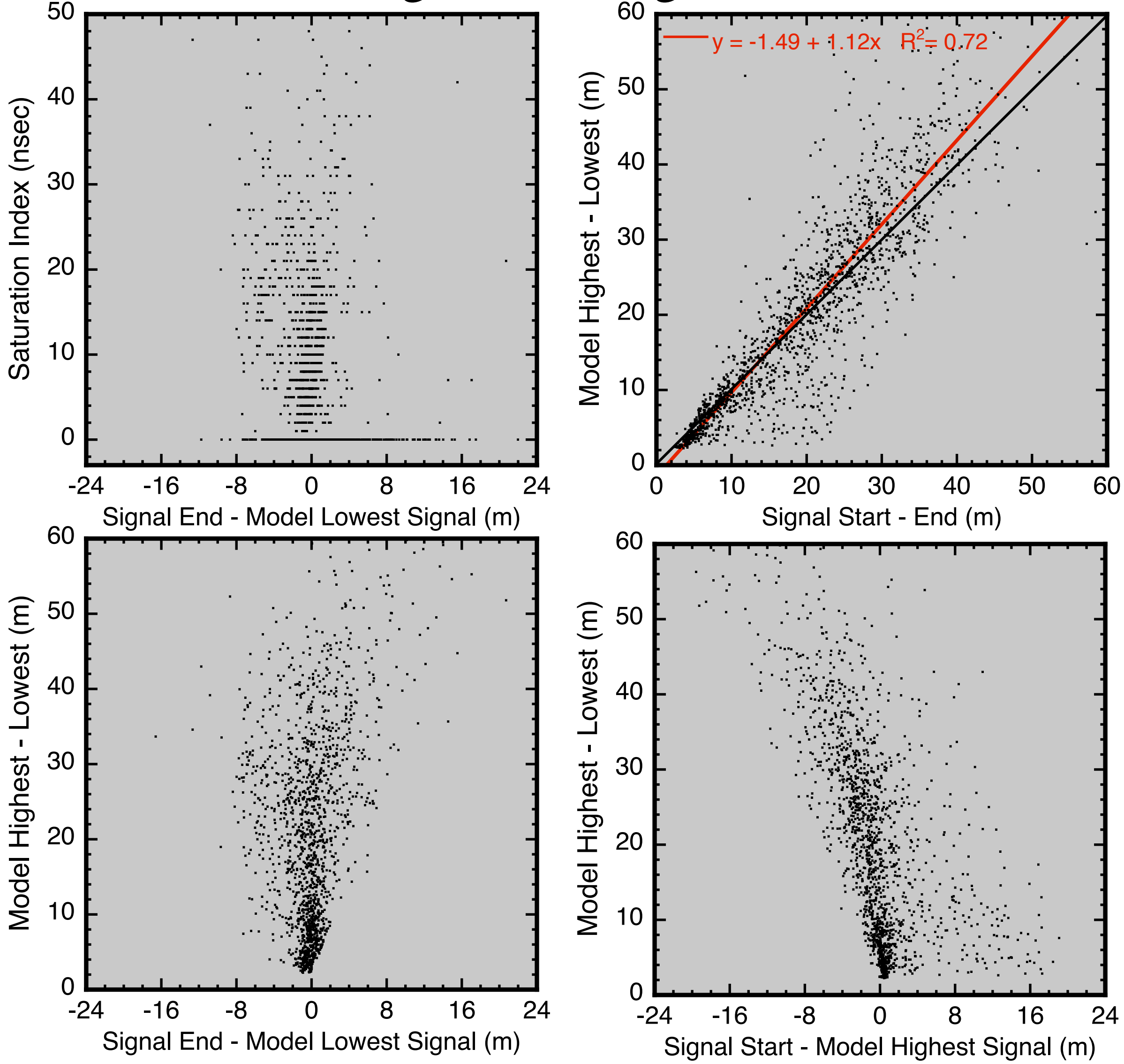








Model Lowest and Highest vs. Signal Threshold Start and End



Task 5 - GLAS pre-launch range offset measurements

Leaders:	J. DiMarzio and X. Sun
Primary Focus:	Determination of instrument range offsets
Approach:	Range offsets derived from pre-launch calibration data were established using instrument team's method for range determination. Recompute range offsets using GSAS computation of range applied to pre-launch calibration data.
Status:	Pre-launch data have been retrieved.
Remaining Work:	Fit pre launch data using GSAS code gaussian fitting procedure and determine range offsets.
Schedule:	12/1/05

Task 6 - Cloud Detection & Atmospheric Forward Scattering Correction

Leaders: C. Shuman, S. Palm, and V. Suchdeo

Primary Focus: Identification and removal of all ice sheet range data significantly affected by clouds (tens to hundreds of meters) as well as identification of slightly impacted ranges (< a few meters) and correction of ranges where possible

Approach: Using 1064 nm channel atmospheric data, establish a reliable 40 Hz cloud flag for cloud filtering across all operations periods as well as a TBD Hz forward scattering range correction

Status: Initial assessment of 1 Hz 532 range correction and 1064 40 Hz cloud top height and integrated backscatter cloud flag completed using L2a 8-day repeat track

Remaining Work: Further testing on the special processing repeated Laser 2a 8-day tracks (088 to 099, Release 524) as well comparison of tracks from other operations periods to Laser 2a data
Using Laser 2a and 2b data, assess quality of 1064 nm results by comparing to simultaneous 532 nm results
Test range correction improvement in elevation accuracy, in combination with saturation range-walk correction, using cross-over residuals and comparisons to independently known elevations (e.g. high-res DEMs for Dry Valleys, Greenland, western US, Pacific NW)

Schedule: TBD

Atmospheric Parameters Derived from 532 Channel

- I_atm_avail: 0/1 flag that tells whether GLA09 and/or GLA11 data are available
- I_erd: Range delay estimate, based on lowest layer detected. A negative number in mm (add to range to correct it)
- I_rdu: Range delay uncertainty. Currently just a fixed percentage (25) of I_erd
- I_cld1_mswf: 0-15 flag indicating relative magnitude of range delay. 0: none – 15: maximum See ATBD for complete description
- I_MRC_af: Number of cloud layers detected

Atmospheric Parameters Derived from 532 Channel

Parameter	Units	Frequency	Products
I_atm_avail	NA	1 Hz	06,11,12,13, 14,15
I_erd	mm	1 Hz	06,11,12,13, 14,15
I_rdu	mm	1 Hz	06,11,12,13, 14,15
I_cld1_mswf	NA	1 Hz	06,11,12,13, 14,15
I_MRC_af	NA	1 Hz	06,11,12,13, 14,15

New GSAS 5.0 1064 Channel Atmospheric Parameters

- I_FRir_cldtop: 40 Hz cloud top height – GLA09. This is produced from a threshold algorithm which includes vertical smoothing (amount can be adjusted. Initial results very good, but need to quantify minimum detectable optical depth.

- I_FRir_intsig: 40 Hz integrated signal – GLA09. This is the sum all 1064 bins above a set threshold. Used to indicate possible presence of cloud even though threshold algorithm failed to detect it.

- I_FRir_qaFlag: 0-15 cloud retrieval quality flag (see next slide for details) for 40 Hz cloud top retrievals.

I_FRir_qaFlag bit values:

Value 15 = No clouds.

Value 14 = Indicates the likely presence of low clouds (< 150 m) based on elevated signal from the two bins above the ground return binthat were not detected directly by the cloud search algorithm. When this occurs, the 40 Hz cloud top height (i_FRir_cldtop) is set to a value of 0.10 km.

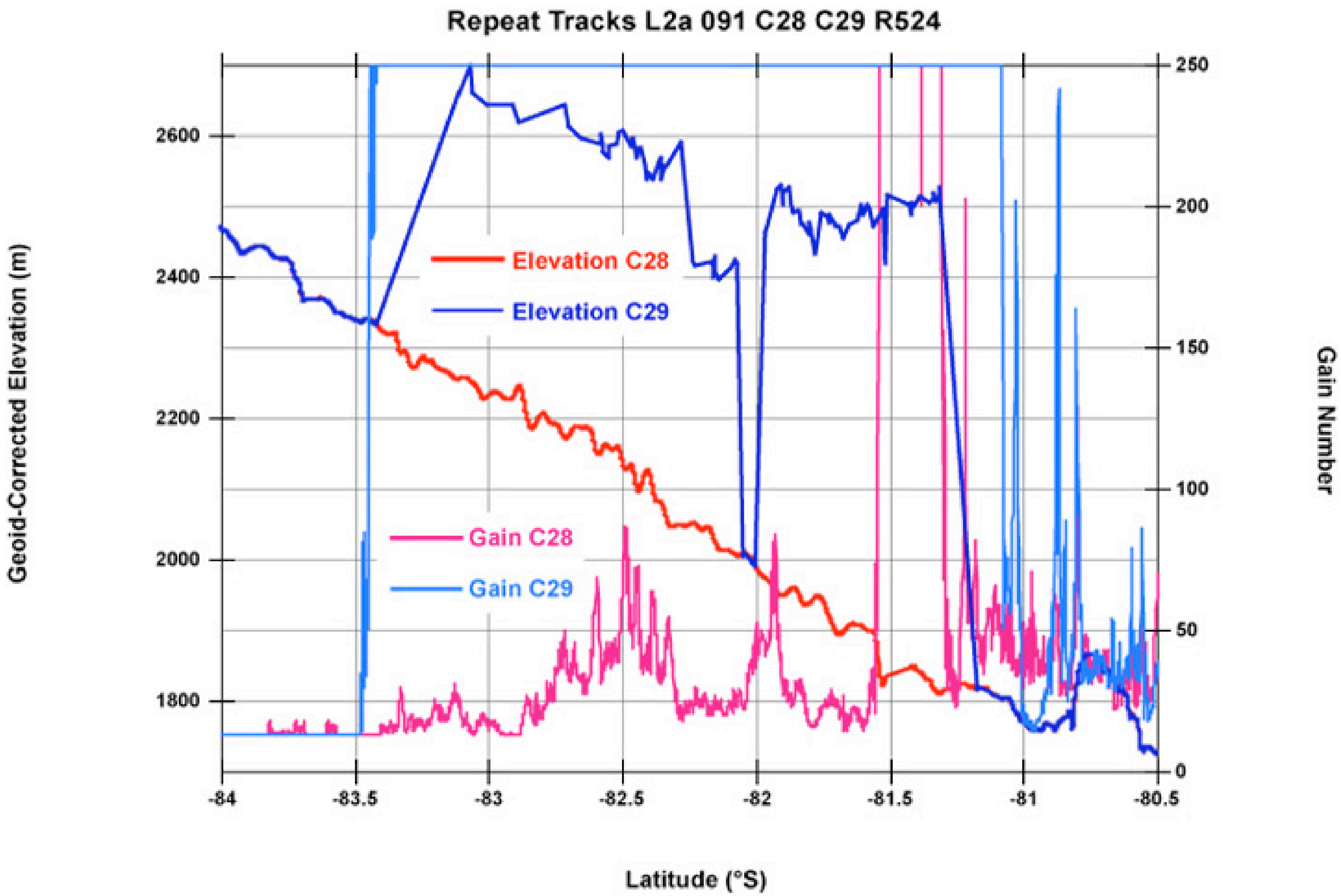
Value 13 = Indicates the possible presence of a cloud based on the value of the integrated signal parameter (i_FRir_intsig) that was not detected directly by the cloud search algorithm. When this occurs, the 40 Hz cloud top height (i_FRir_cldtop) is set to a value of 10.0 km.

Value 0 - 12 = Cloud detected by cloud search algorithm with higher numbers indicating a stronger average signal from the region starting at cloud top and extending 500 m below cloud top height.

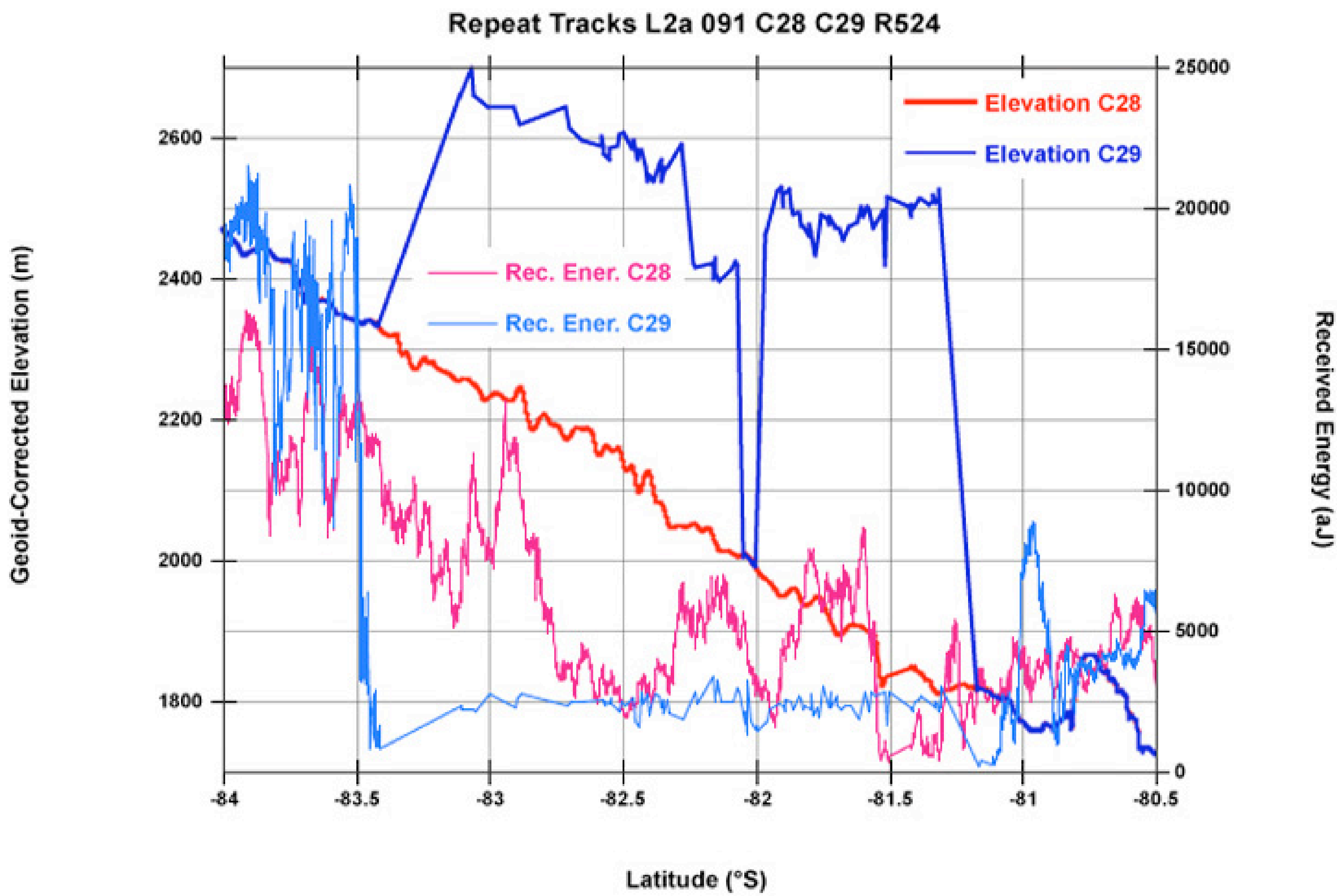
Future Products to be Derived from 1064 Channel

- 1 Hz Cloud Optical Depth. A crude measure of optical depth with 4-5 different levels (i.e. 0.0-0.5; 0.5-1.0; 1.0-1.5, etc.)
- Range delay estimate based on above
- More robust cloud detection involving more vertical averaging and a TBD amount of horizontal averaging.

Cloud Impacts - L2a Track 091 - Case 1



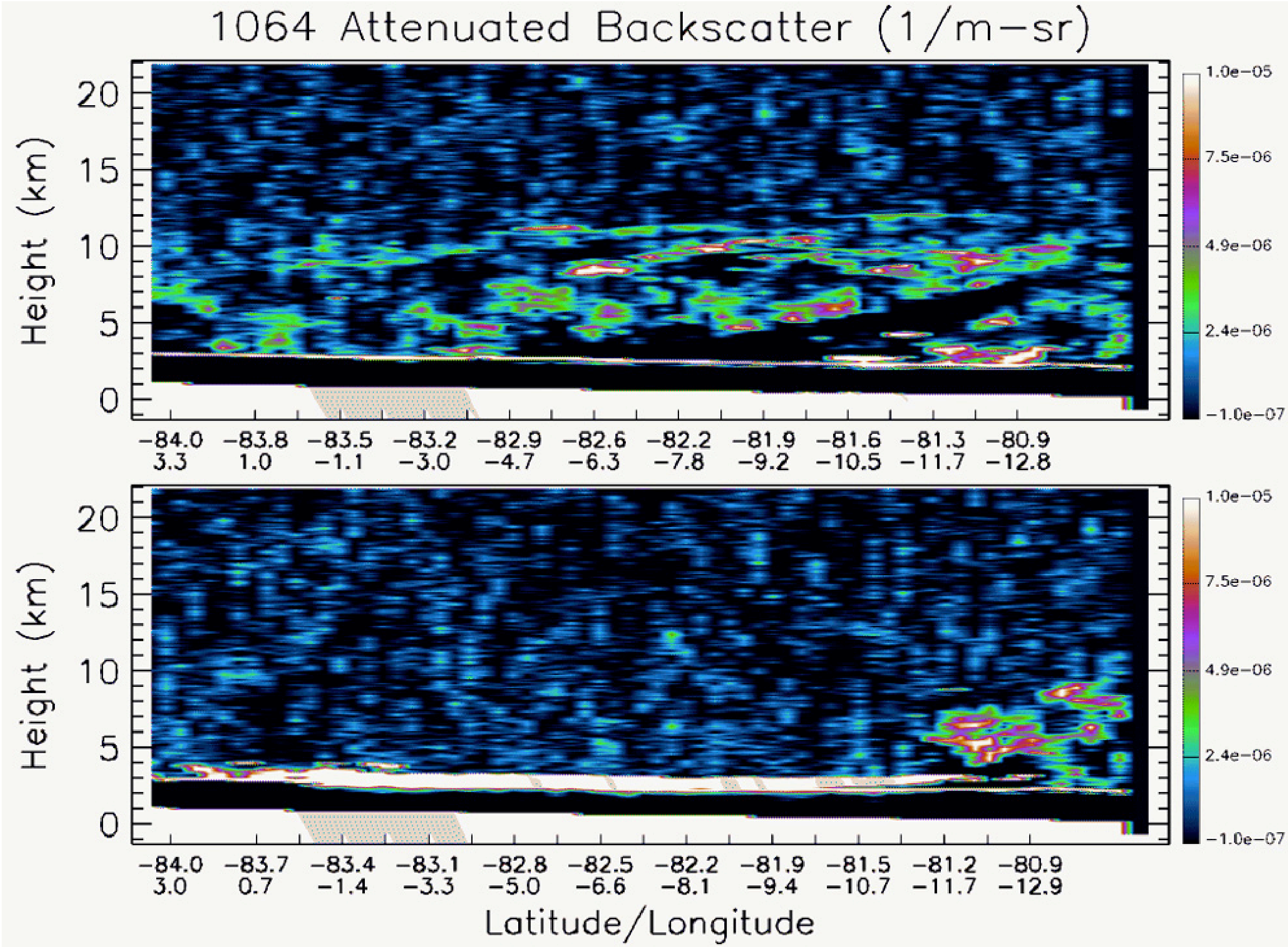
Cloud Impacts - L2a Track 091 - Case 1



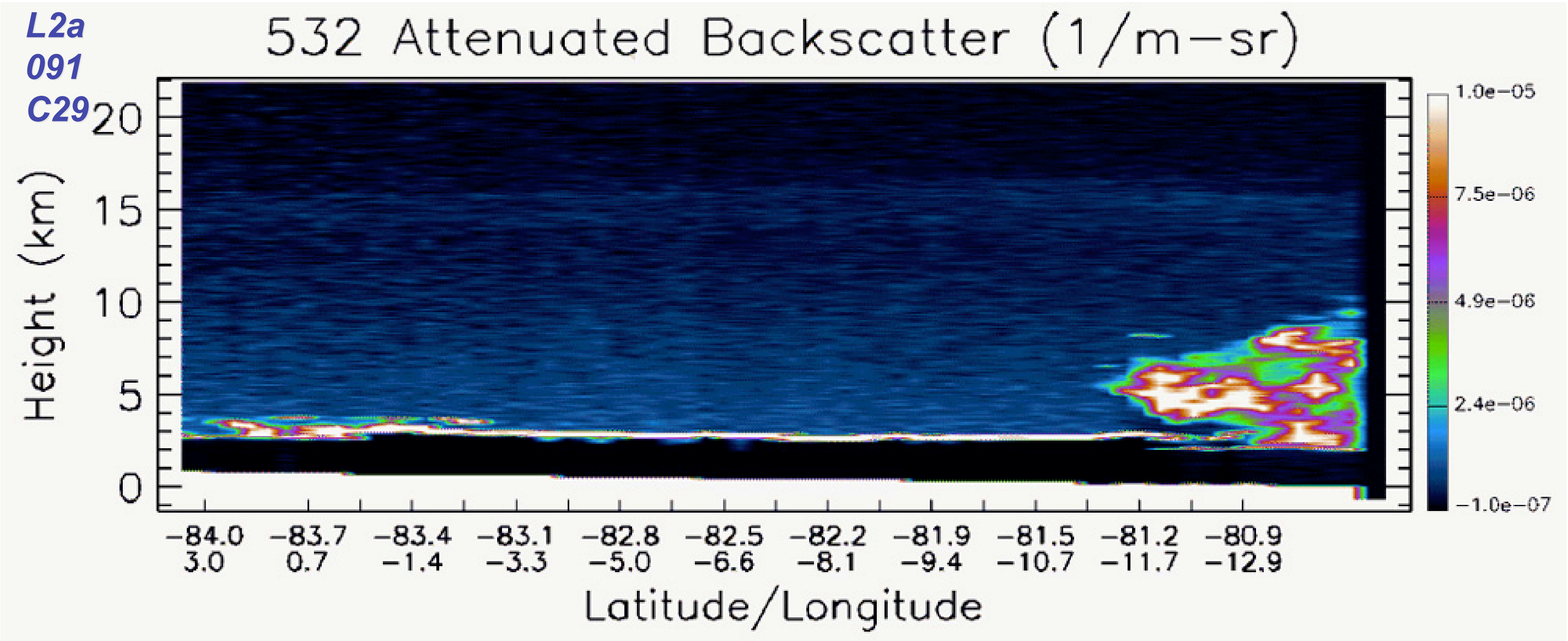
Cloud Impacts - L2a Track 091 - Case 1

L2a
091
C28

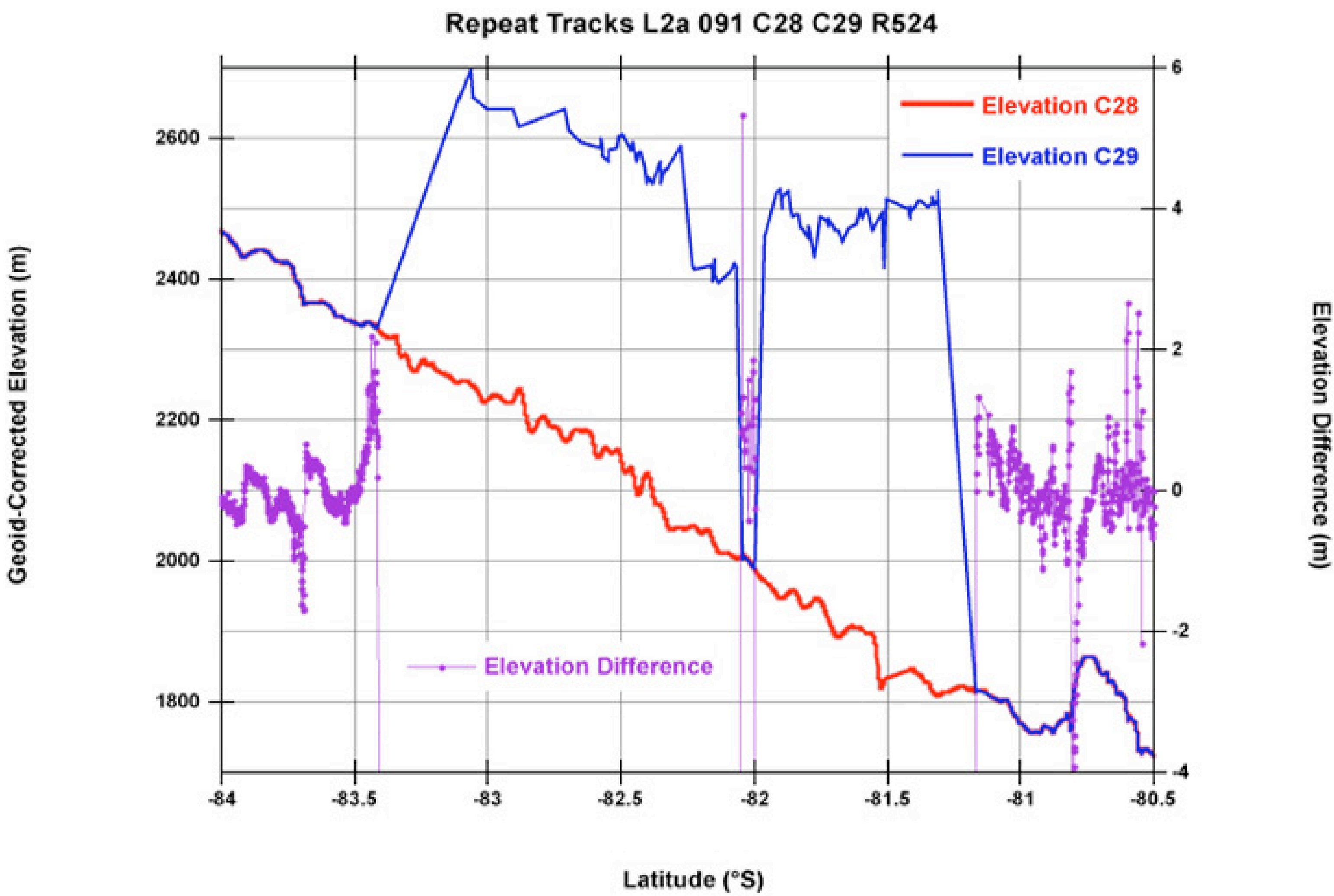
L2a
091
C29



Cloud Impacts - L2a Track 091 - Case 1

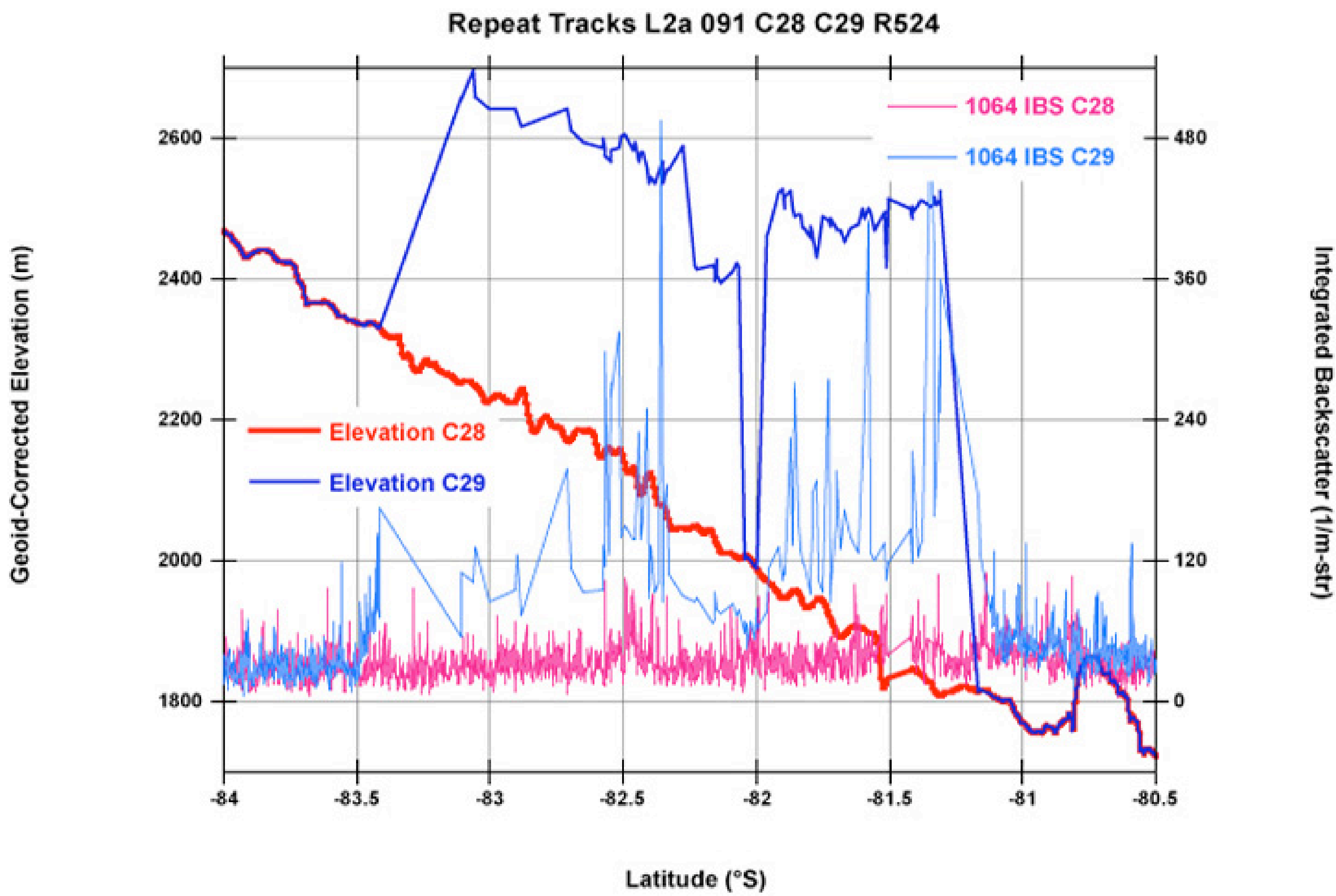


Cloud Impacts - L2a Track 091 - Case 1

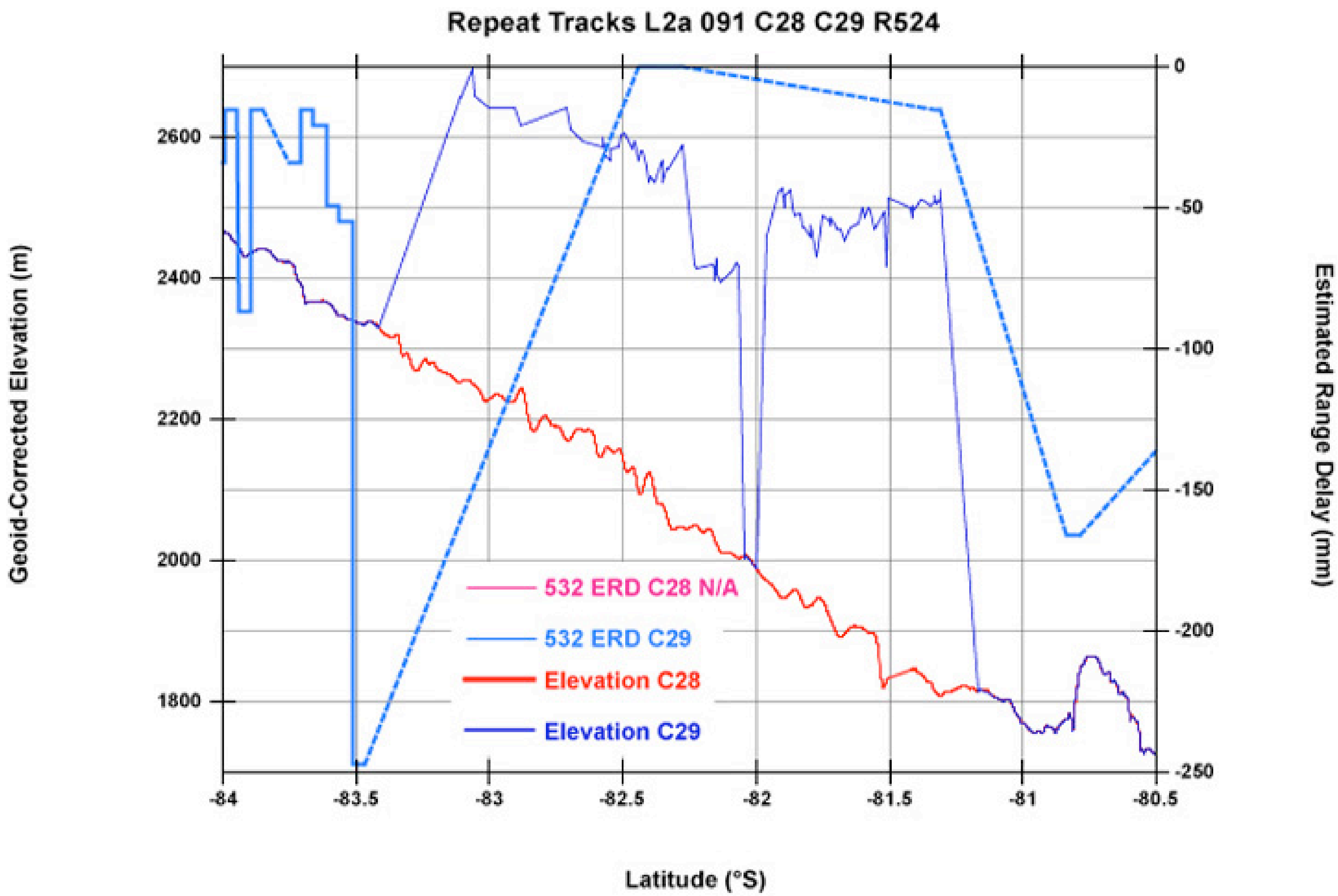


Note slope impact (sensitive to cross track alignment)

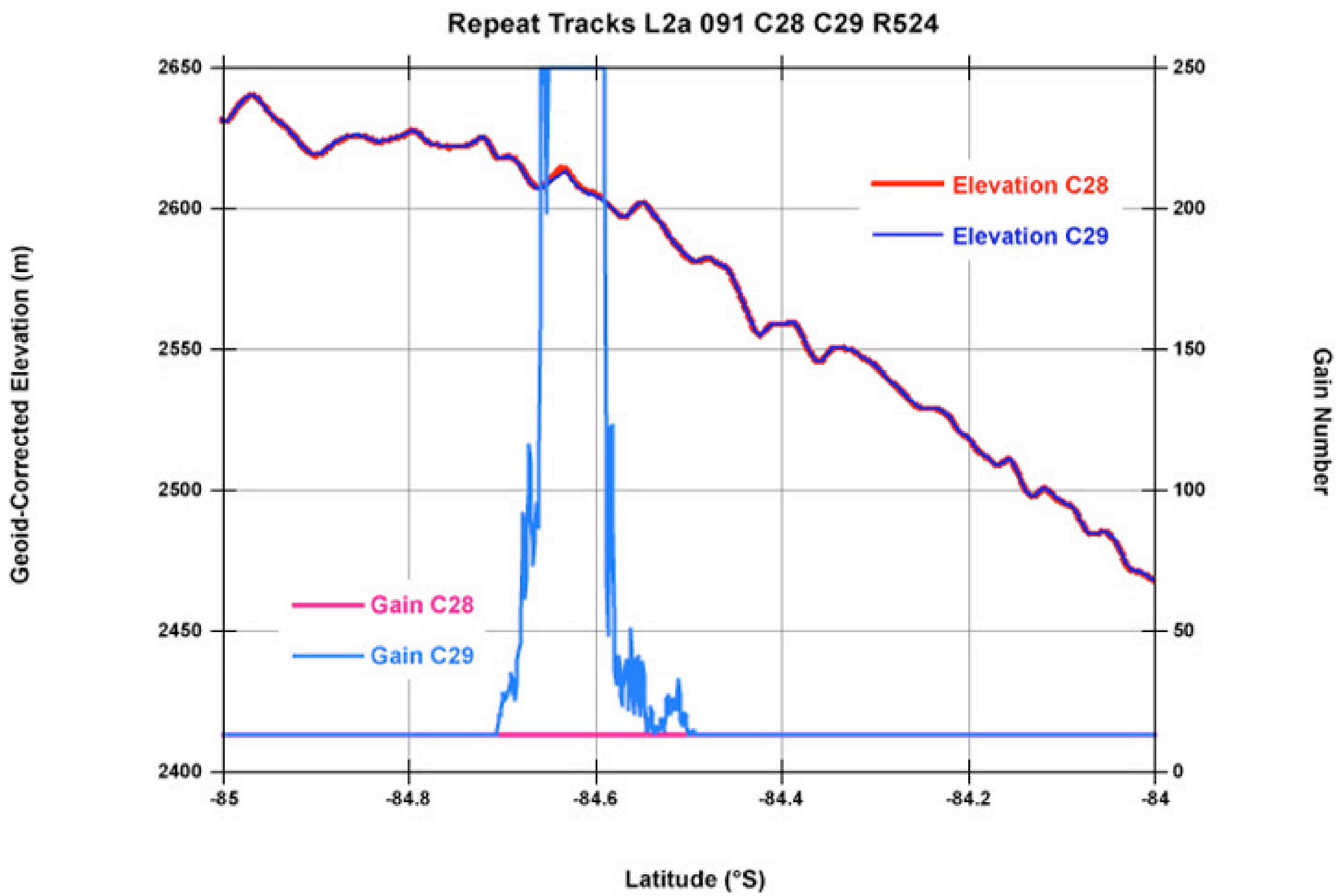
Cloud Impacts - L2a Track 091 - Case 1



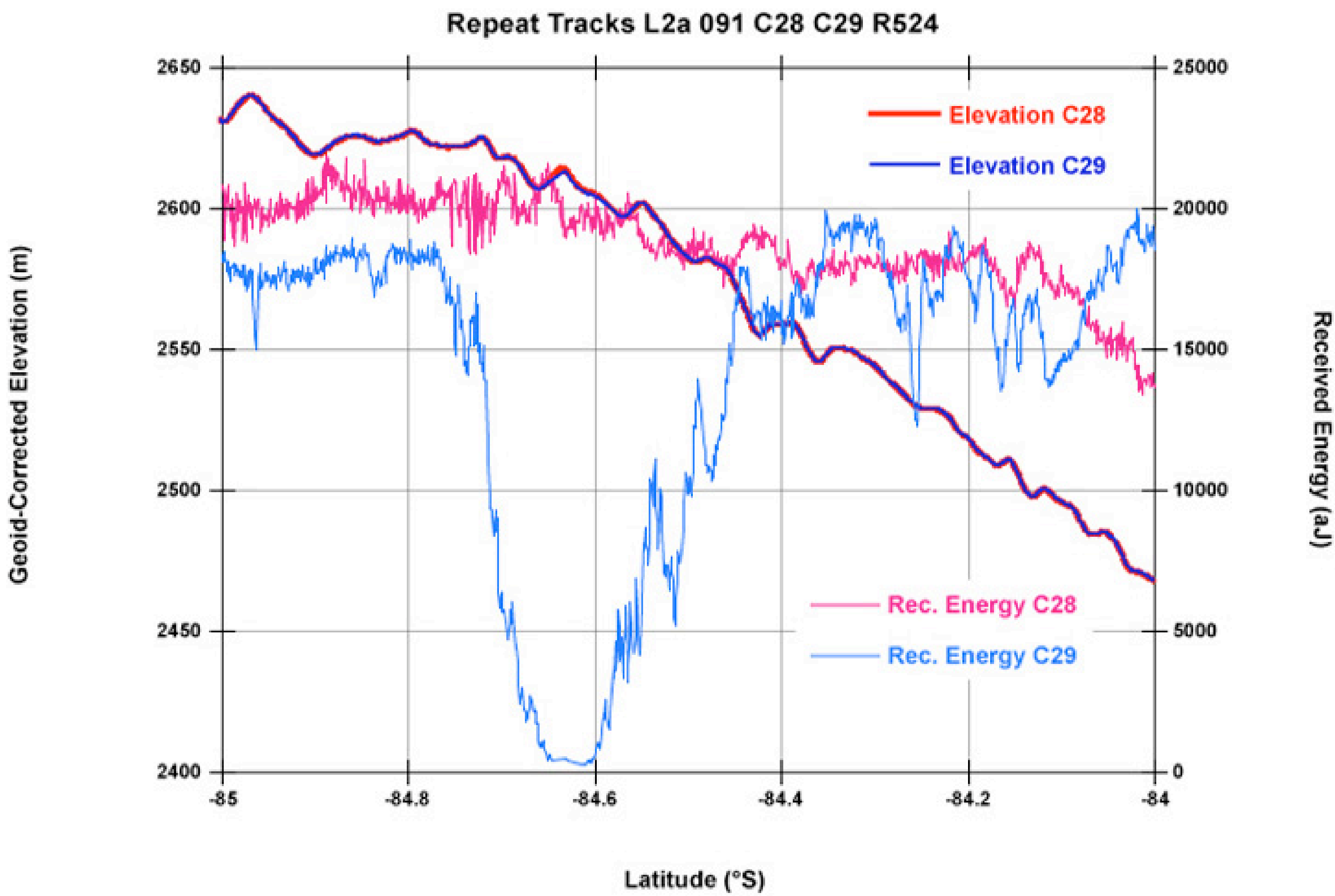
Cloud Impacts - L2a Track 091 - Case 1



Cloud Impacts - L2a Track 091 - Case 2

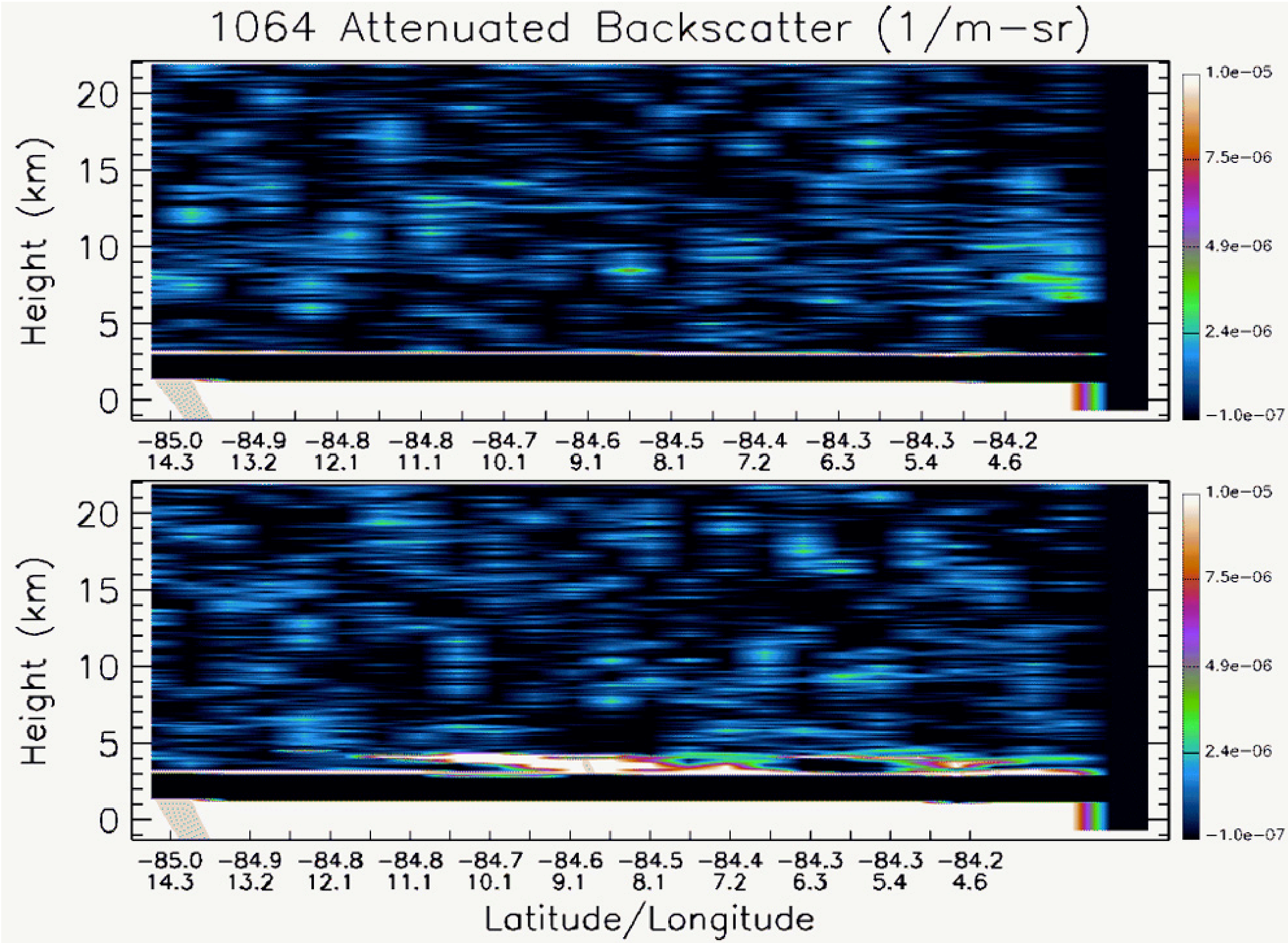


Cloud Impacts - L2a Track 091 - Case 2



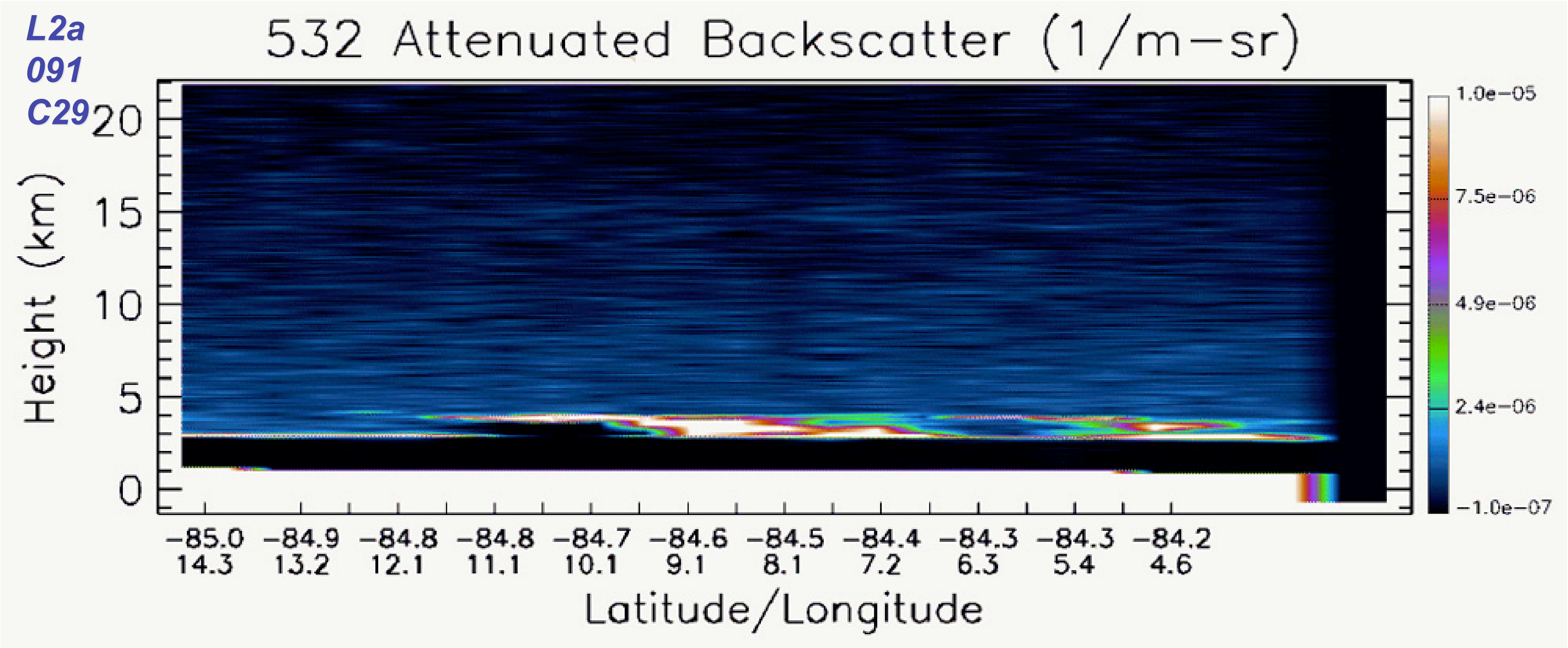
Cloud Impacts - L2a Track 091 - Case 2

L2a
091
C28

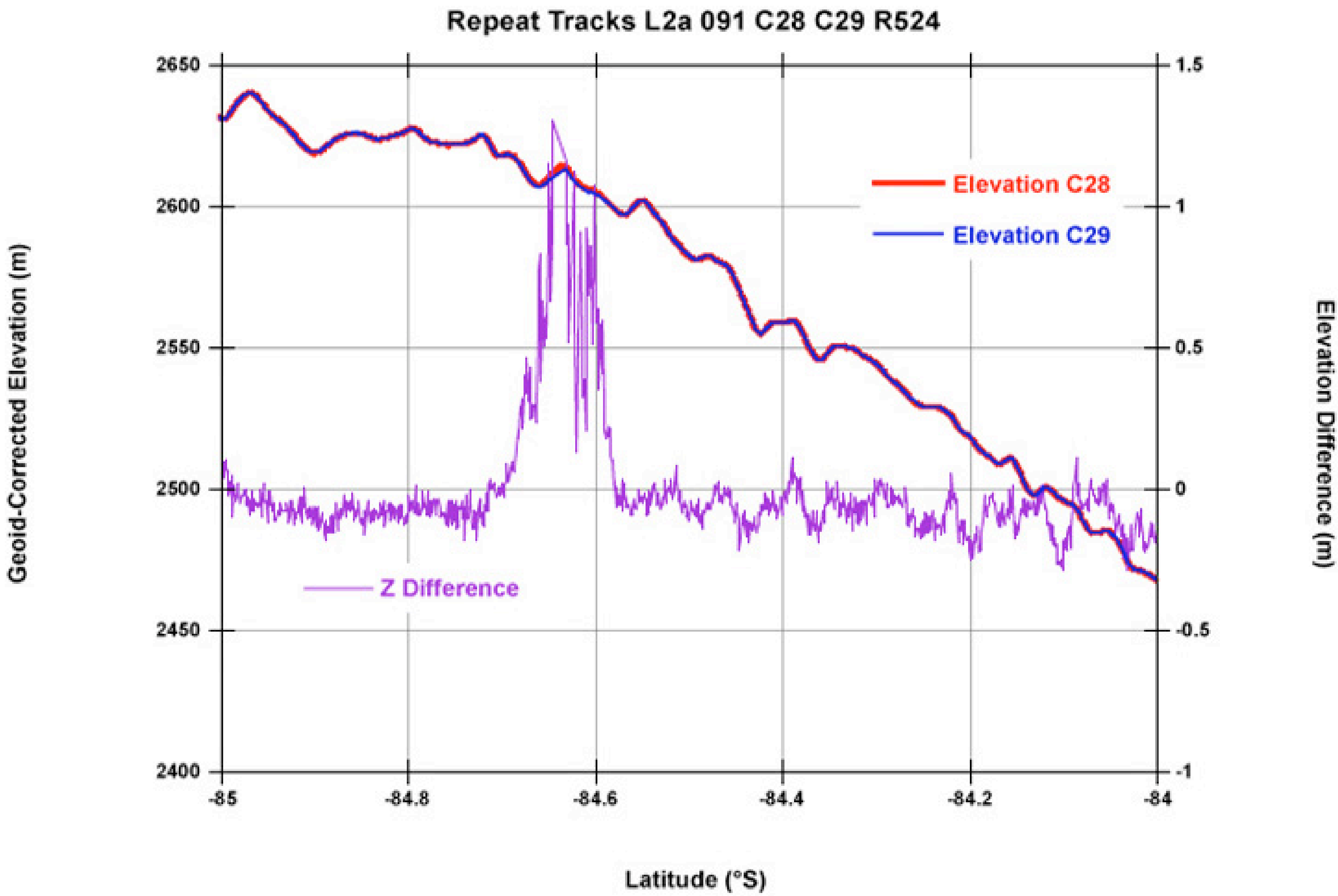


L2a
091
C29

Cloud Impacts - L2a Track 091 - Case 2

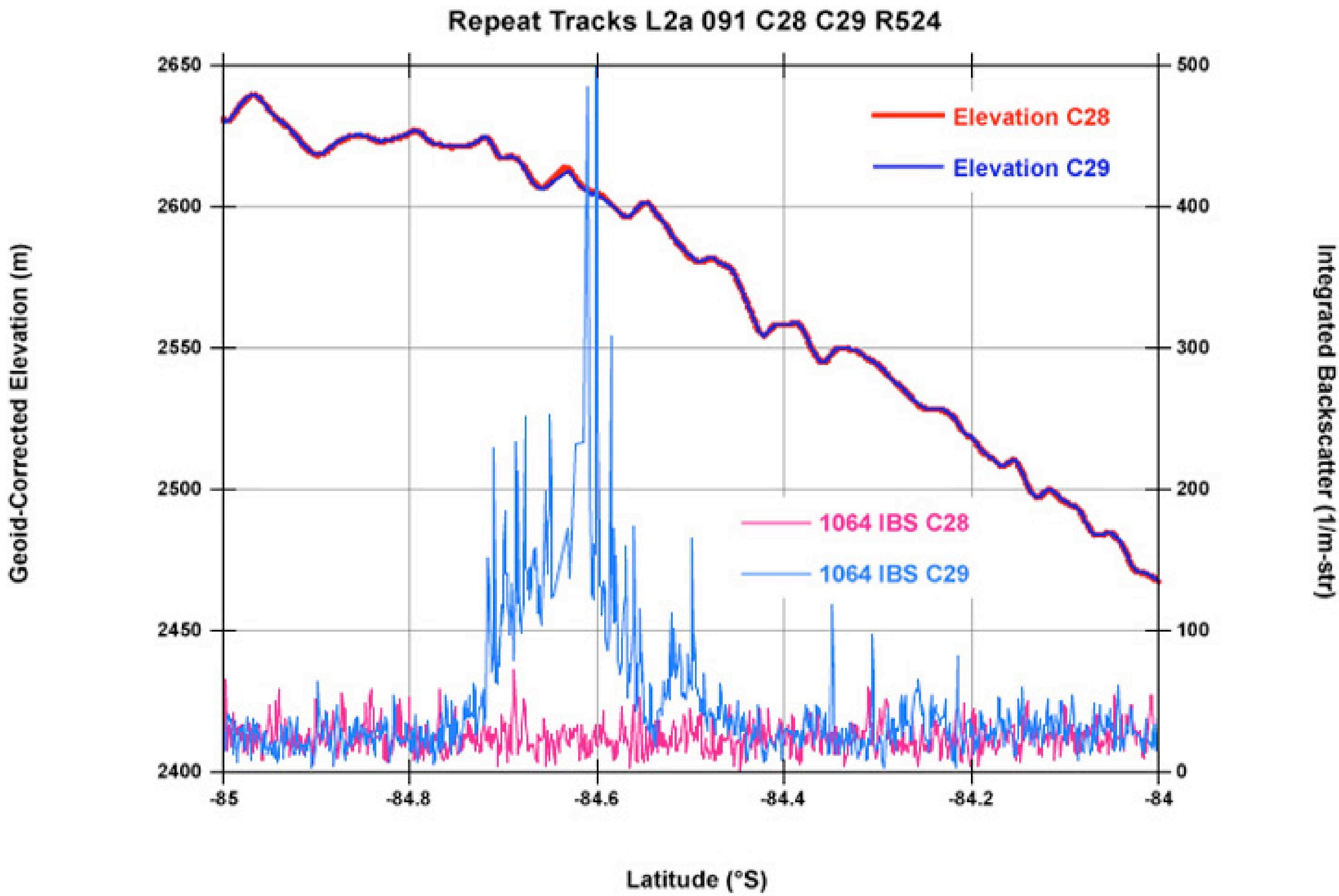


Cloud Impacts - L2a Track 091 - Case 2

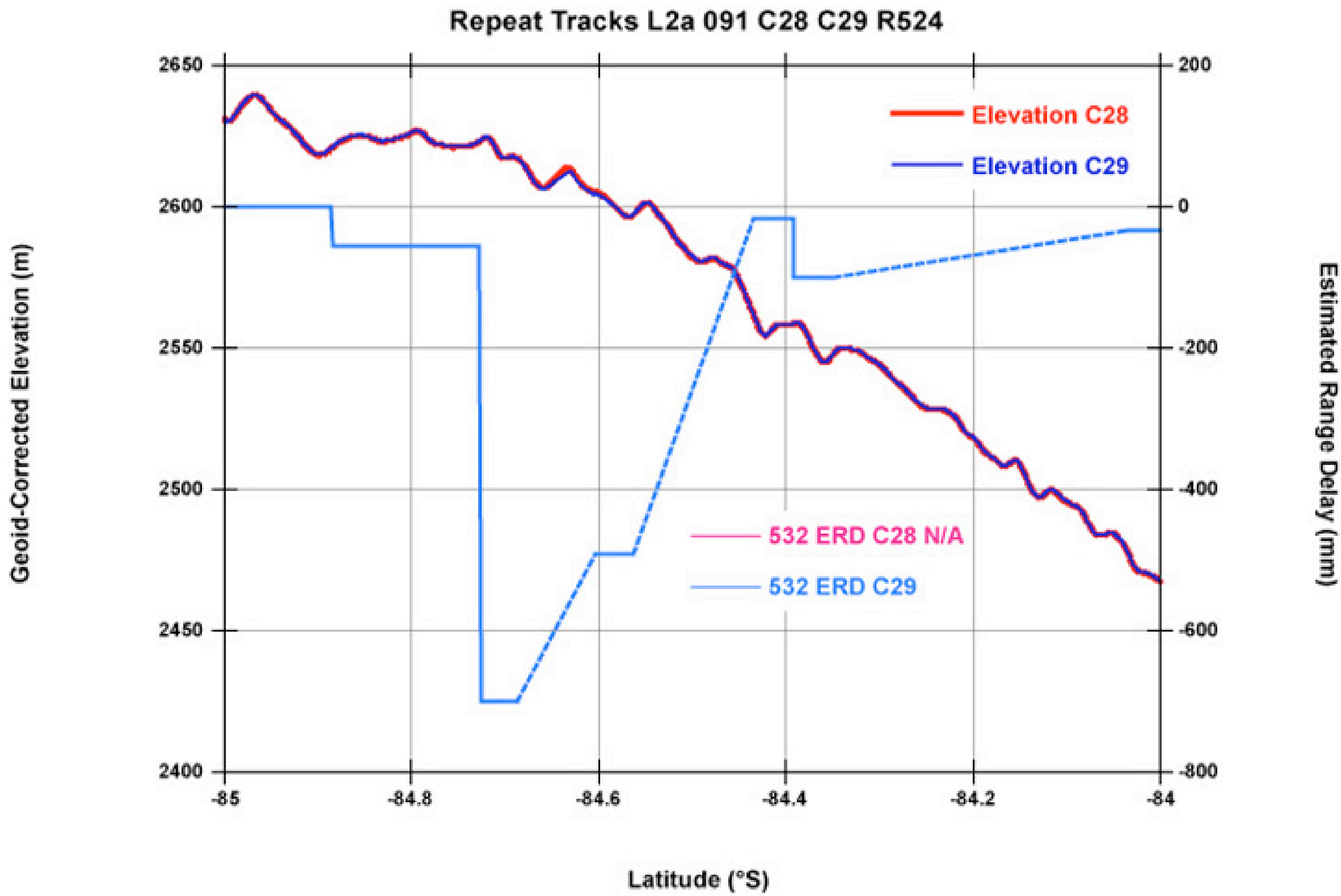


Note slope impact (sensitive to cross track alignment)

Cloud Impacts - L2a Track 091 - Case 2



Cloud Impacts - L2a Track 091 - Case 2



Saturation Correction Studies

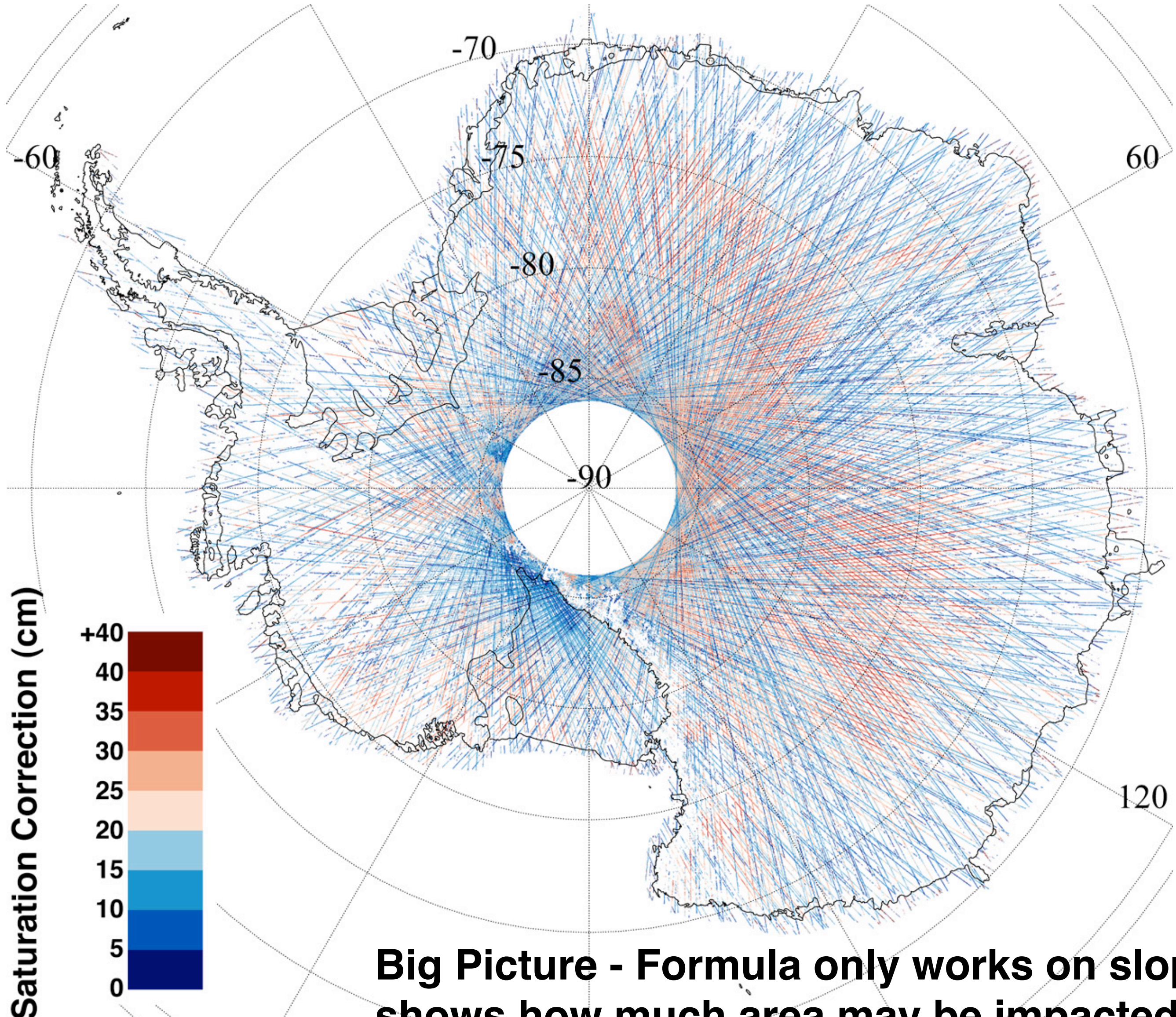
As part of the group effort to understand saturation correction and its impacts, I had Vijay apply the formula:

=IF Gain=13 AND RecEnergy>13100, THEN
SatCorr = (0.000149*(RecEnergy-13100)*0.149896229))

to all of Laser 2a data across Antarctica and then map the results. The next slide relates to that activity. The high plateau area of East Antarctica dominates but also note the 'low correction' area at the interior 'end' of the Ross Ice Shelf and the 'no correction' area along the TransAntarctic mountains. Clouds certainly impact the pattern. Also, I've applied the same correction to Laser 2a R21 and Laser 3a R22 Track 0071 data across Lake Vostok. The later slides relate to that activity.

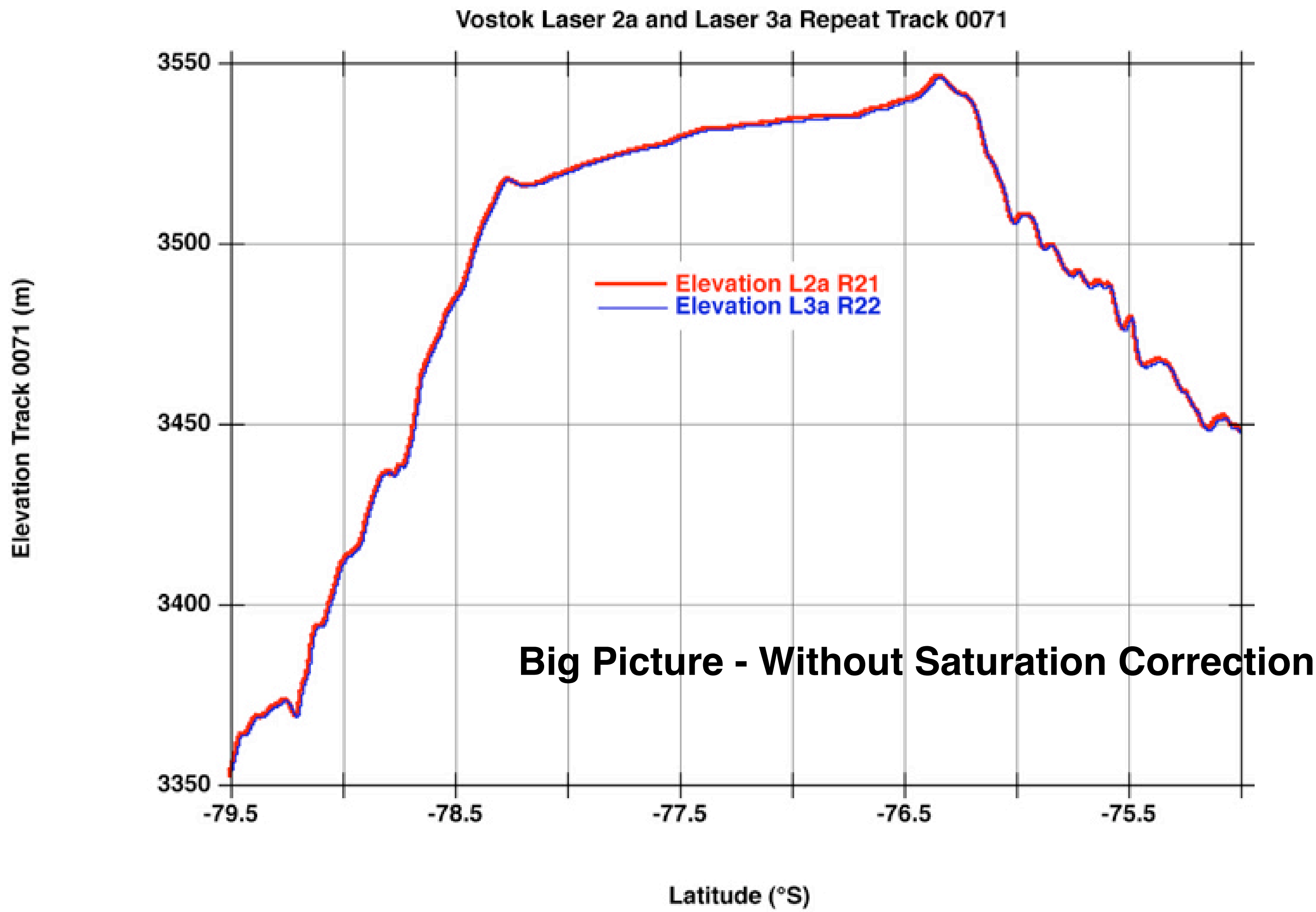
Caveat - we did not apply the 'two bin' rule and know that the formula does not (yet) work for slopes above ~0.5 degrees.

Laser 2a Saturation Correction Map

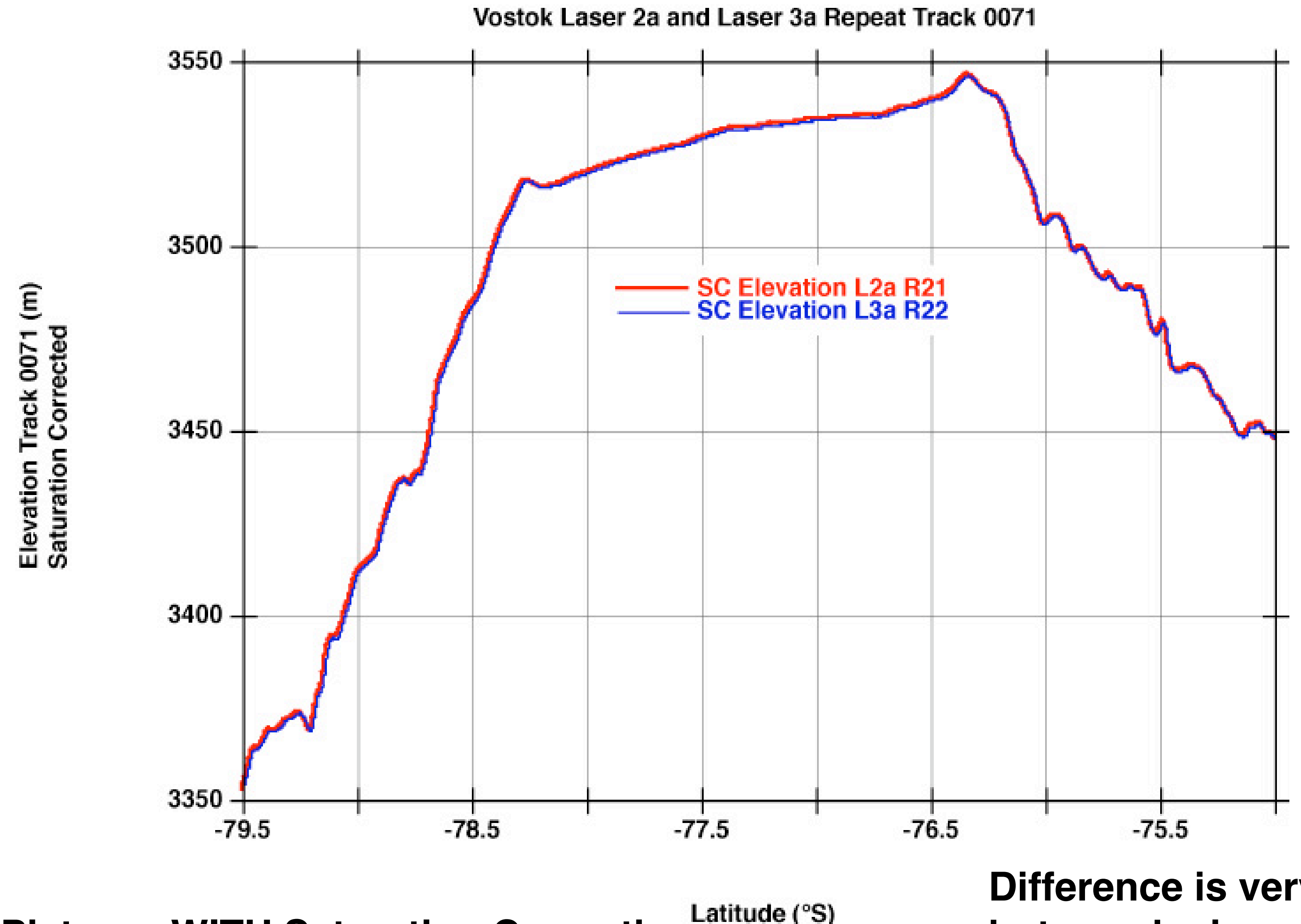


Big Picture - Formula only works on slopes to ~0.5 deg but shows how much area may be impacted in L2a, L3a…

Laser 2a/3a Comparison Track 0071



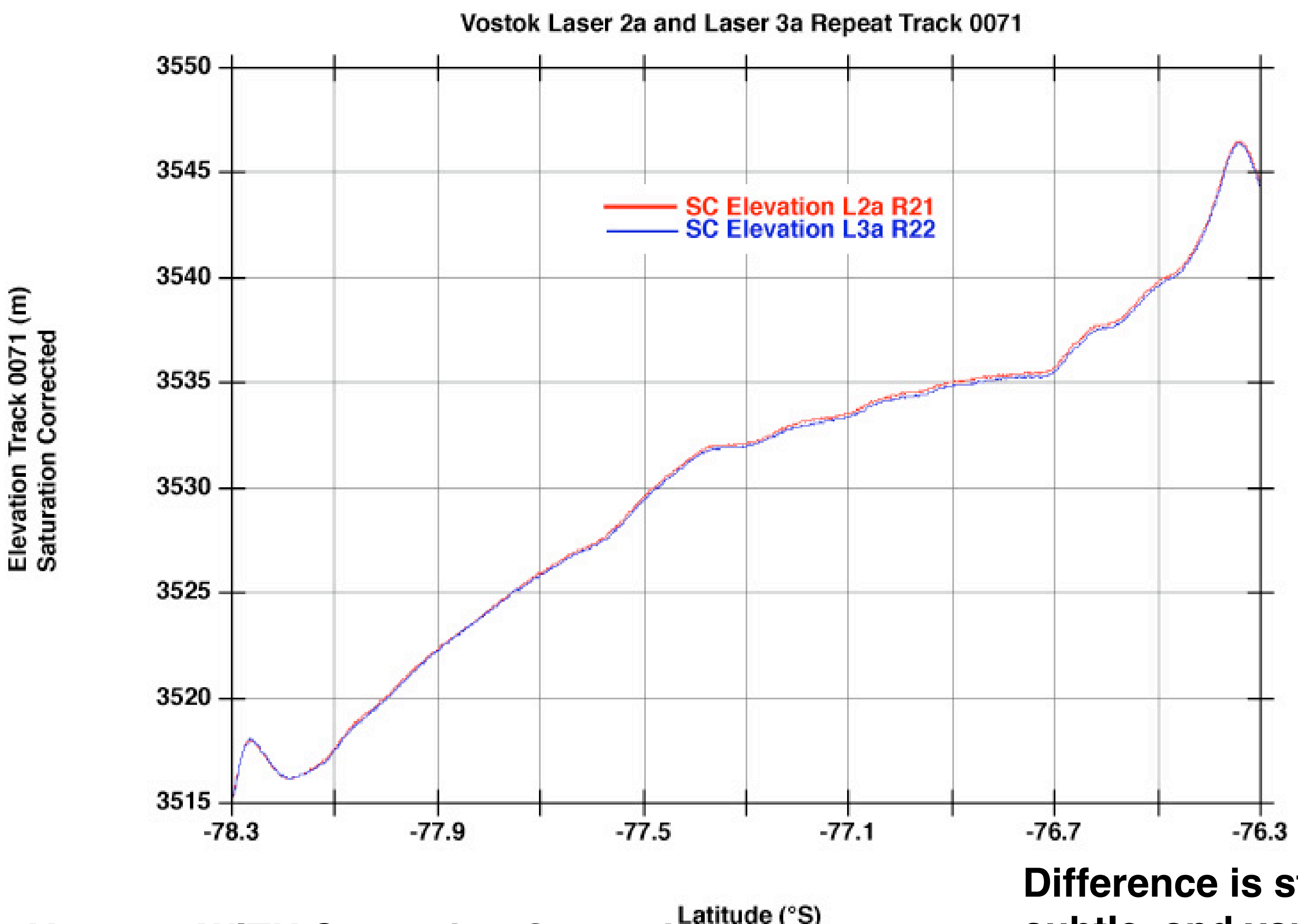
Laser 2a/3a Comparison Track 0071



Big Picture - WITH Saturation Correction

Difference is very subtle but may be important

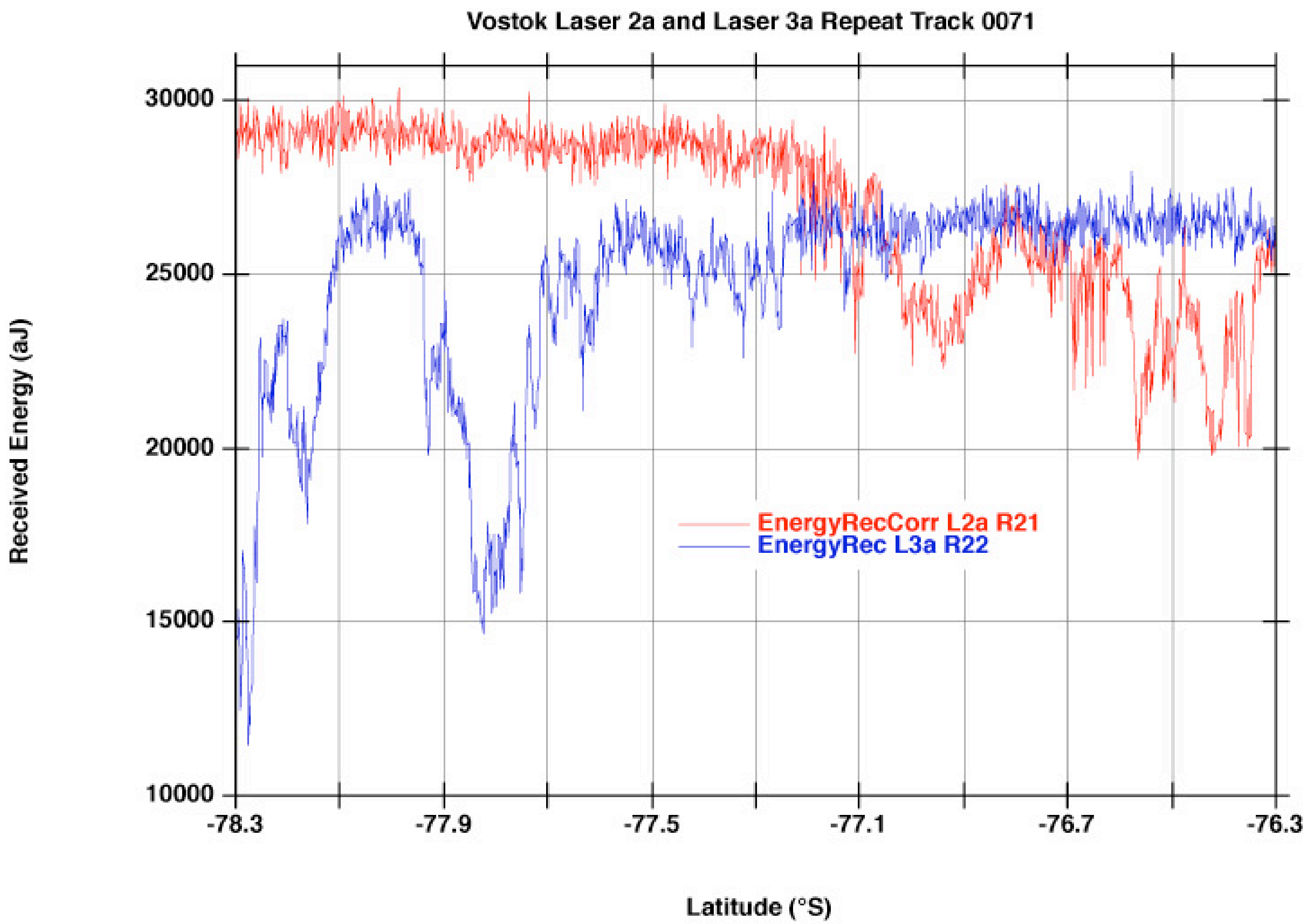
Laser 2a/3a Comparison Track 0071



Difference is still very subtle, and varies

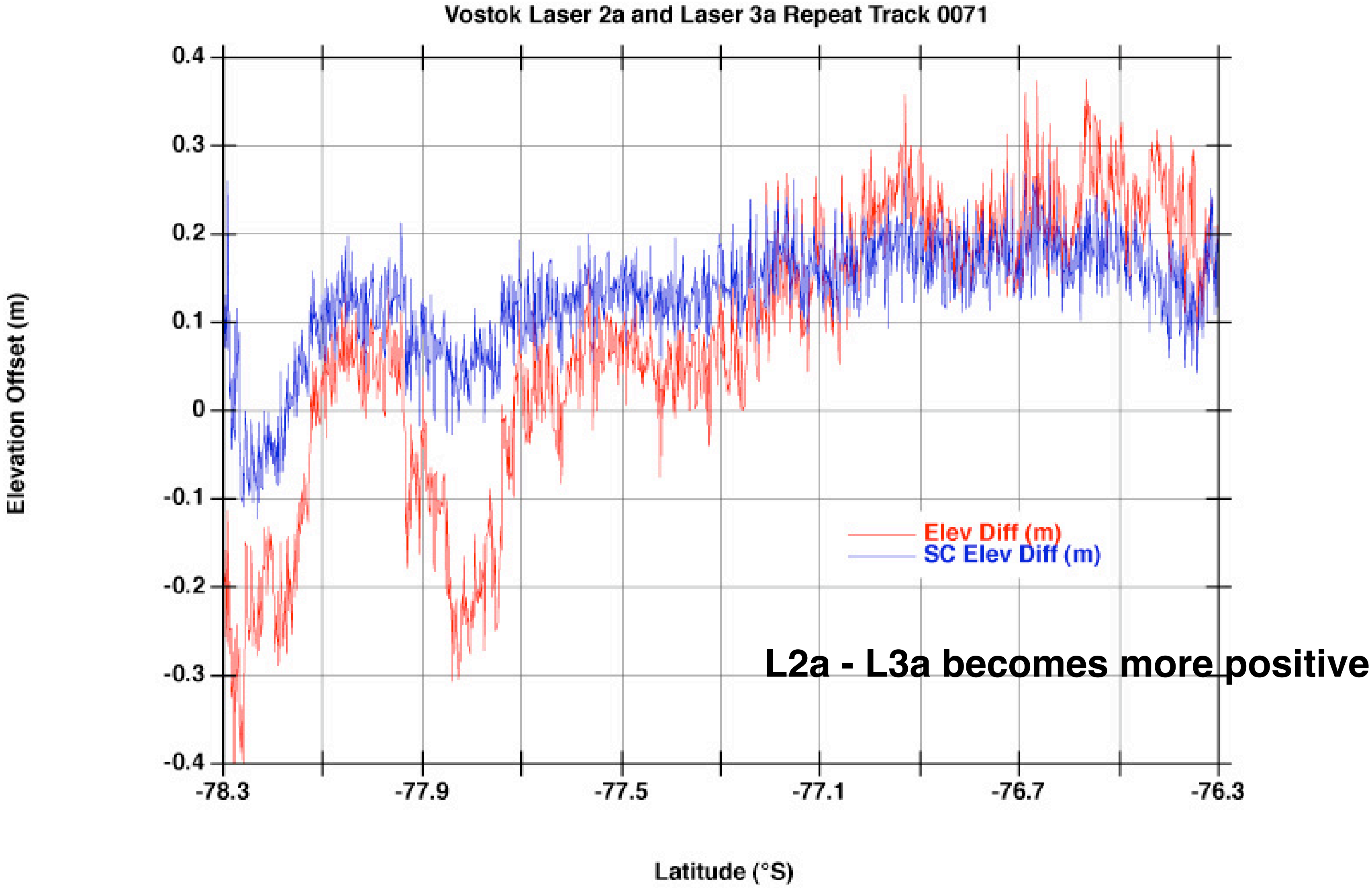
Just Vostok - WITH Saturation Correction

Laser 2a/3a Comparison Track 0071



But energy varies distinctly - most likely due to atmosphere (thin clouds?)

Laser 2a/3a Comparison Track 0071



Elevation offset improves with sat. correction but ‘damped’ variations remain..

Illustration of Cloud Impacts - Summary

1). Short Δt repeat tracks provide an independent means of assessing cloud impacts and cloud 'flagging' parameters
2). 1064 integrated backscatter shows promise but needs further testing on additional tracks and/or cloud conditions
3). 1064 cloud top values are noisy but may be useful for further defining broad cloud masses
4). Both 1064 40 Hz parameters 'react' to clouds that can have little to no apparent elevation impact (however, this may enable studies of 'clearest-sky' data)
5). 532 ERD has limited value as it does not penetrate thicker clouds and is effectively available only for certain ops periods and is calculated at 1 Hz
6). Additional parameters such as std. dev. of gaussian fit?

Further work is clearly needed, especially for gain or received energy filtering (not perfect but relatively easy to apply) as well as assessing thinnest clouds that have small elevation impact but can influence saturation correction at the 10s of cm level.

Task 7 - Catalog Anomalous Waveforms (The Zoo)

Leaders: J. DiMarzio and A. Brenner

Primary Focus: Document unexpected waveform occurrences not properly handled by GSAS code

Approach: Create web-based database to which anomalous waveforms can be submitted by data users, with fields for the submitter to complete that identify the waveform, the data release, and why it is thought to be anomalous
This would guide GSAS developers in future revisions, and be available to users to see examples of what types of waveforms cause problems

Status: Decided to use “mantis” problem tracking software as a web-based tool for input of waveform examples

Remaining Work: Set up and customize mantis instance on the SCF web pages.

Schedule: 12/1/2005

Task 8 - Range Error Contribution to Geolocation Imprecision

Leaders: S. Luthcke, B. Schutz, and C. Carabajal

Primary Focus: Possible high-frequency errors in geolocation

Approach: Assess if there is high-frequency geolocation error not accounted for by current PAD and POD calibration techniques that is due to errors in range determination (overlaps with the activities of the PAD Working Group)

Status: Initial discussion of L3a anomalies in Integrated Residual Analysis (IRA) results held.

Remaining Work: After correction for saturation and atmosphere range errors, re-run IRA on L3a. Complete waveform matching to high-res DEM assessment of shot-to-shot geolocation accuracy

Schedule: TBD

Task 9 - Footprint Ellipticity and Size Estimation

Leaders: B. Schutz, D. Yi, and D. Harding

Primary Focus: Ice sheet slope and roughness estimation
Range uncertainty due to elliptical footprint orientation on sloped surfaces

Approach: Provide footprint ellipticity and size estimates consistent with algorithm used for estimation of slope and roughness ($1/e^2$ major and minor axes)
Where LPA image S/N poor due to low energy, use stacked LPA images or LRS image

Status: Requirements needed for slope and roughness calculation defined
$1/e^2$ diameters from LPA image were used in Task 10 algorithm validation
Validated that UT LRS $1/e^2$ axes are similar to instrument team results
Observed that LPA $1/e^2$ results differ somewhat from LRS results and LPA axes lengths “toggle” at high-frequency

Remaining Work: Finalize and implement $1/e^2$ major and minor axes determination at UT
(replacing constant energy threshold method currently used)
Document derivation method and accuracy of results

Schedule: TBD

GSFC LRS vs. UT LRS and LPA 1/e^2 footprint diameters (meters)
Mean diameters computed over short data segments

	VTCW sec	UTC sec	GPS sec (from midnight)	DOY		Minor Axis GSFC LRS (Marcos)	Minor Axis University of Texas LRS (4 image averaged)	Minor Axis University of Texas LPA (1 sec averaged)	Minor Axis University of Texas LPA (1 sec stacked)	Major Axis GSFC LRS (Marcos)	Major Axis University of Texas LRS (4 image averaged)	Major Axis University of Texas LPA (1 sec averaged)	Major Axis University of Texas LPA (1 sec stacked)
LASER 1	99098798	99055598	84411	51	20.Feb.2003	**49.82**	49.50	n/a	0.00	**106.58**	106.70	n/a	82.38
	99101589	99058389	87202	51	20.Feb.2003	**48.79**	150.00	n/a	0.00	**105.58**	230.00	n/a	101.39
	100126970	100083770	75783	63	04.Mar.2003	**53.09**	50.70	55.30	56.99	**108.92**	114.20	146.00	149.95
	100137800	100094600	86613	63	04.Mar.2003	**53.02**	51.20	57.00	58.12	**108.94**	114.70	147.00	151.60
	101966988	101923788	15001	85	26.Mar.2003	**47.28**	n/a	58.00	64.22	**61.51**	n/a	153.00	166.31
	102000891	101957691	48904	85	26.Mar.2003	**47.28**	54.30	57.00	61.66	**61.51**	93.30	153.00	166.56
LASER 2A	117851816	117808616	88629	268	25.Sep.2003	**47.42**	47.00	40.70	41.60	**85.48**	86.60	83.50	85.12
	117852627	117809427	3040	269	26.Sep.2003	**46.85**	48.00	41.80	42.35	**85.35**	87.20	83.60	85.18
	118953611	118910411	67224	281	08.Oct.2003	**48.17**	46.50	42.30	42.68	**87.68**	89.80	89.40	89.94
	119232200	119189000	86613	284	11.Oct.2003	**47.42**	48.70	43.10	43.60	**91.19**	95.60	93.50	95.35
	119275413	119232213	43426	285	12.Oct.2003	**47.44**	50.30	46.30	47.49	**91.73**	98.00	99.20	100.79
	119342280	119299080	23893	286	13.Oct.2003	**47.72**	48.50	43.00	43.57	**94.56**	98.00	97.20	98.68
	119361801	119318601	43414	286	13.Oct.2003	**48.30**	48.60	43.00	43.43	**94.38**	98.60	100.00	101.36
	119406081	119362881	87694	286	13.Oct.2003	**49.29**	51.20	50.00	48.83	**97.63**	102.90	100.00	101.33
	119513000	119469800	21813	288	15.Oct.2003	**47.19**	47.80	43.20	43.52	**99.45**	102.70	102.90	103.26
	120528200	120485000	86613	299	26.Oct.2003	**47.99**	48.80	44.00	44.80	**100.47**	105.90	105.80	107.92
	120960761	120917561	87174	304	31.Oct.2003	**48.88**	49.90	45.10	46.00	**97.98**	104.70	107.80	109.35
	121047825	121004625	87838	305	01.Nov.2003	**48.49**	51.20	48.80	49.98	**96.51**	103.50	105.50	107.96
	121222779	121179579	3592	308	04.Nov.2003	**49.26**	51.20	49.80	48.24	**97.71**	104.00	109.00	110.05
	122364609	122321409	22222	321	17.Nov.2003	**51.53**	53.20	52.40	53.04	**93.63**	100.00	104.00	105.69
	122429001	122385801	86614	321	17.Nov.2003	**51.62**	52.20	50.60	51.45	**80.50**	84.20	83.70	85.46
	122493800	122450600	65013	322	18.Nov.2003	**51.84**	52.40	49.50	51.20	**82.02**	86.00	84.50	86.62
LASER 2B	130377600	130334400	86413	48	17.Feb.2004	**50.00**	48.40	42.80	43.24	**88.07**	89.70	91.90	92.83
	130378476	130335276	87289	48	17.Feb.2004	**48.62**	48.30	43.60	43.81	**87.87**	90.30	92.70	92.72
	130961757	130918557	65770	55	24.Feb.2004	**52.05**	50.40	43.40	44.45	**85.62**	90.00	91.00	92.50
	131134834	131091634	66047	57	26.Feb.2004	**50.57**	50.20	45.00	45.52	**80.36**	81.50	86.00	86.53
	131479481	131436281	65094	61	01.Mar.2004	**55.93**	53.10	46.00	46.55	**79.51**	79.00	83.70	84.57
	131738600	131695400	65013	64	04.Mar.2004	**56.38**	54.10	48.00	48.92	**78.10**	79.30	84.20	85.62
	132062809	132019609	43622	68	08.Mar.2004	**58.56**	56.70	50.90	52.69	**78.64**	80.40	84.40	87.90
	132495174	132451974	43987	73	13.Mar.2004	**66.87**	61.90	57.90	58.48	**89.34**	92.50	92.80	94.04
	132667216	132624016	43229	75	15.Mar.2004	**67.83**	66.50	60.50	61.32	**92.25**	94.90	96.50	97.45
	132667399	132624199	43412	75	15.Mar.2004	**68.52**	66.40	59.60	60.36	**91.17**	95.10	94.20	97.66
LASER 2C	138216004	138172804	62417	139	18.May.2004	**59.21**	63.70	57.00	56.16	**96.75**	95.90	84.00	96.30
	138221734	138178534	68147	139	18.May.2004	**61.03**	62.00	53.60	60.36	**96.53**	97.50	92.50	97.66
	138738058	138694858	66071	145	24.May.2004	**53.96**	52.40	42.00	43.15	**110.37**	105.80	97.00	97.58
	139341821	139298621	65034	152	31.May.2004	**41.44**	71.10	n/a	34.55	**120.41**	110.70	n/a	75.80
	139433989	139390789	70802	153	01.Jun.2004	**59.20**	64.60	n/a	26.45	**117.81**	114.30	n/a	79.75
	139493063	139449863	43476	154	02.Jun.2004	**68.65**	70.20	n/a	26.09	**117.21**	110.40	n/a	78.89
	139515151	139471951	65564	154	02.Jun.2004	**51.32**	64.90	n/a	28.91	**122.82**	115.20	n/a	82.95
LASER 3A	150163200	150120000	13	278	04.Oct.2004	**50.78**	51.30	44.90	45.41	**57.52**	59.00	55.70	55.92
	150769033	150725833	87446	284	10.Oct.2004	**46.85**	50.70	46.20	50.73	**55.00**	59.30	56.40	54.77
	151461998	151418798	89211	292	18.Oct.2004	**46.40**	51.50	49.80	50.16	**54.66**	59.20	57.80	57.16
	152129002	152085802	65015	300	26.Oct.2004	**45.19**	46.30	41.90	42.60	**54.65**	57.00	57.30	57.65
	152864762	152821562	23175	309	04.Nov.2004	**46.83**	48.50	43.00	43.76	**54.51**	58.00	56.80	57.36
	153194999	153151799	7812	313	08.Nov.2004	**46.19**	47.50	41.90	42.72	**55.10**	58.10	56.60	57.39
	153230599	153187399	43412	313	08.Nov.2004	**46.42**	49.00	44.00	46.94	**54.77**	58.80	56.50	54.98
LASER 3B	161980877	161937677	67290	48	17.Feb.2005	**44.58**	44.50	40.00	40.16	**53.20**	54.50	54.80	54.95
	162000000	161956800	13	49	18.Feb.2005	**45.24**	45.50	41.00	41.98	**49.96**	52.10	52.00	53.31
	162475399	162432199	43412	54	23.Feb.2005	**46.23**	51.90	50.00	50.63	**58.08**	68.30	72.10	74.16
	162497001	162453801	65014	54	23.Feb.2005	**47.28**	53.40	53.00	53.62	**74.72**	88.20	92.60	94.39
	163233291	163190091	23704	63	04.Mar.2005	**47.76**	52.60	51.10	51.98	**67.72**	81.10	84.60	86.86
	164161060	164117860	87473	73	14.Mar.2005	**46.31**	52.00	49.20	50.19	**63.85**	72.70	79.30	82.01
	164289799	164246599	43412	75	16.Mar.2005	**47.86**	53.60	55.80	56.92	**79.48**	70.00	87.50	88.82
	164788200	164745000	23413	81	22.Mar.2005	**47.32**	53.40	52.30	53.92	**74.57**	78.70	84.60	87.20
	164810494	164767294	45707	81	22.Mar.2005	**48.39**	52.80	53.00	52.42	**70.22**	75.40	80.00	82.07

GSFC and UT use different measurement methods, but the diameters from LRS images are in general agreement.

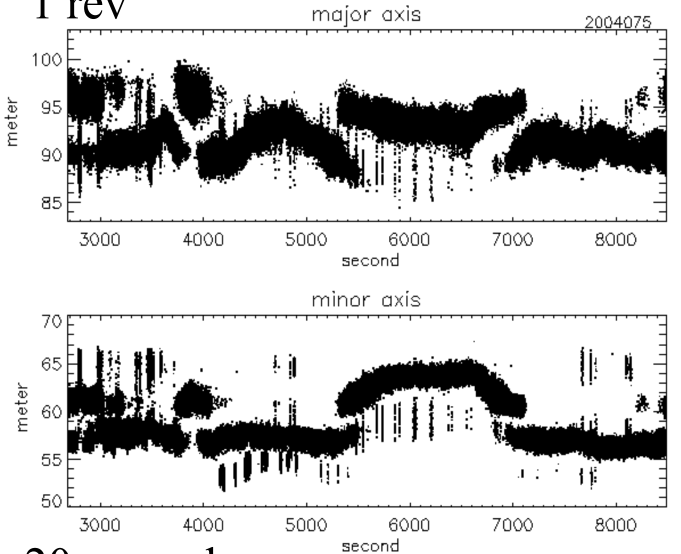
UT LPA diameters agree less well with the LRS results, and can be larger or smaller than the LRS diameters.

The LPA major axis for Laser 1 is substantially larger than for the LRS because the LPA images looked much more elliptical than the LRS images.

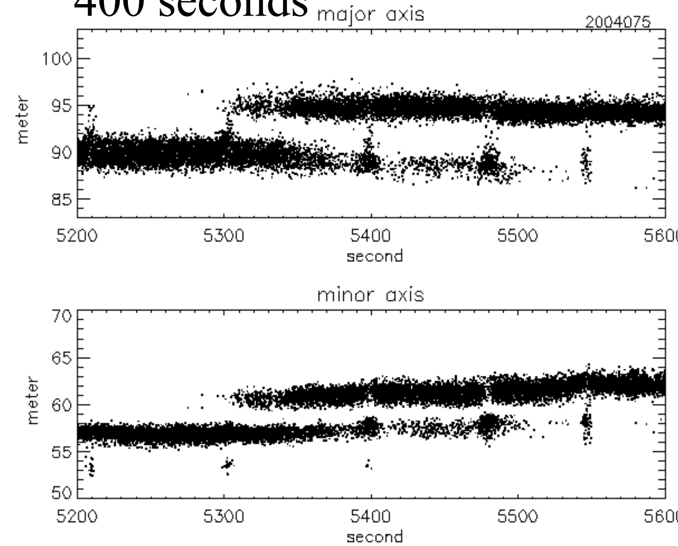
Are LPA or LRS images the better choice to use?

UT LPA $1/e^2$ footprint diameters (meters)

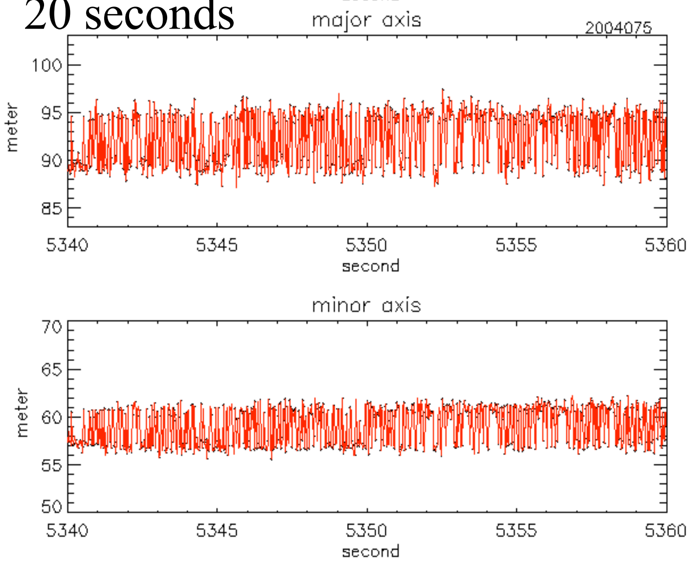
1 rev



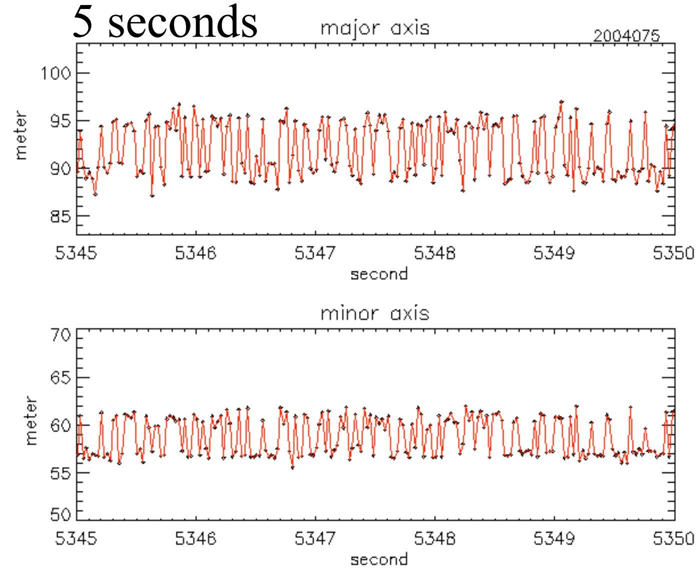
400 seconds



20 seconds



5 seconds



<u>L2B (day 75)</u>

LPA diameters oscillate between two states at high frequency with the diameters varying by ~ 5 m, accounting for the structure in the 1 rev plot.

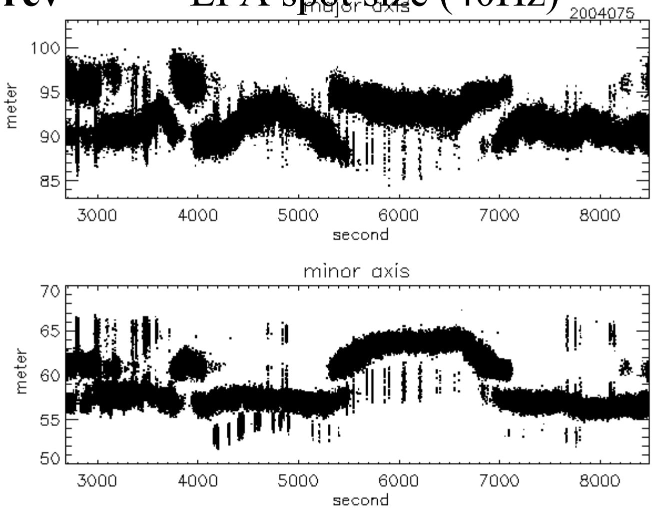
Is this oscillation real? Is this representative of other days and other periods?

If real, is ~ 5 m variations significant enough that we need to continue reporting size at 40 Hz?

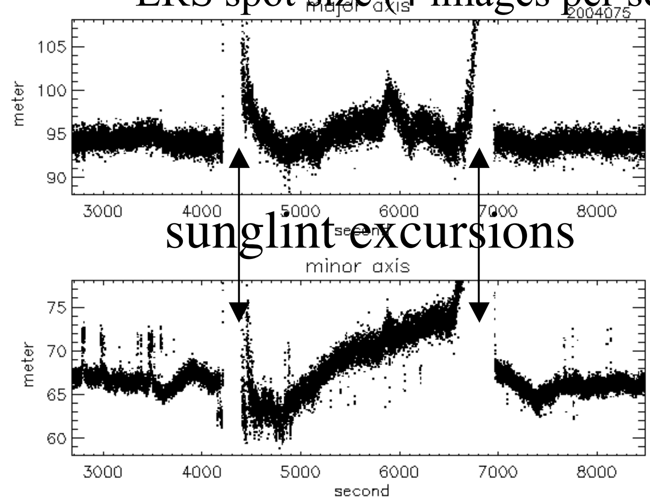
UT LRS and LPA $1/e^2$ footprint diameters (meters)

1 rev

LPA spot size (40Hz)

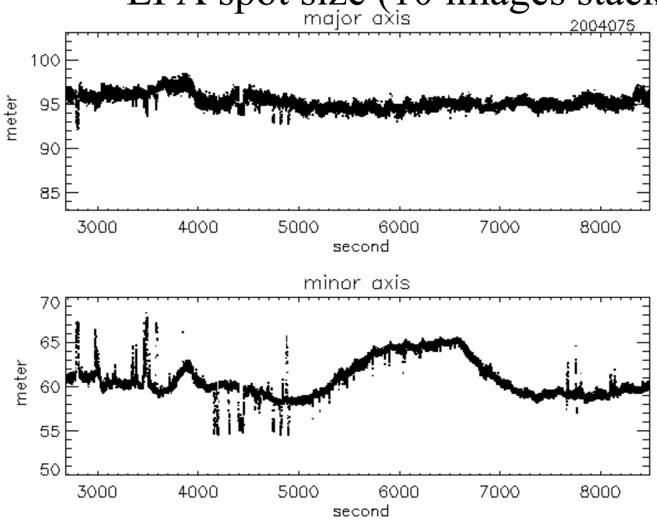


LRS spot size (4 images per second)

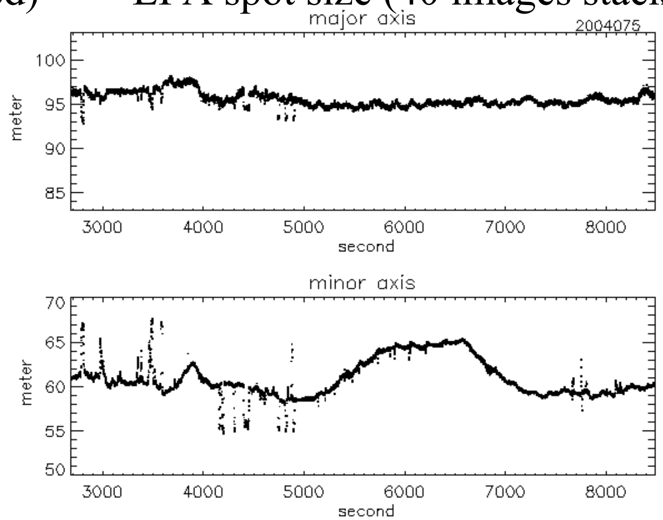


LRS diameters exhibit excursions at the terminator due to sunglint contamination, but do not show the size oscillation.

LPA spot size (10 images stacked)

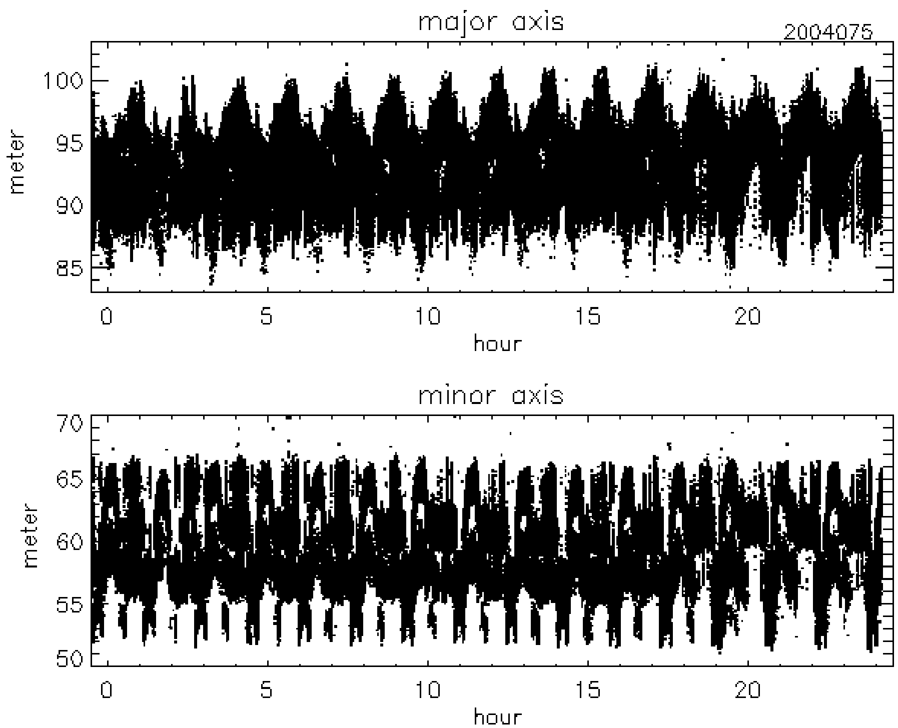


LPA spot size (40 images stacked)

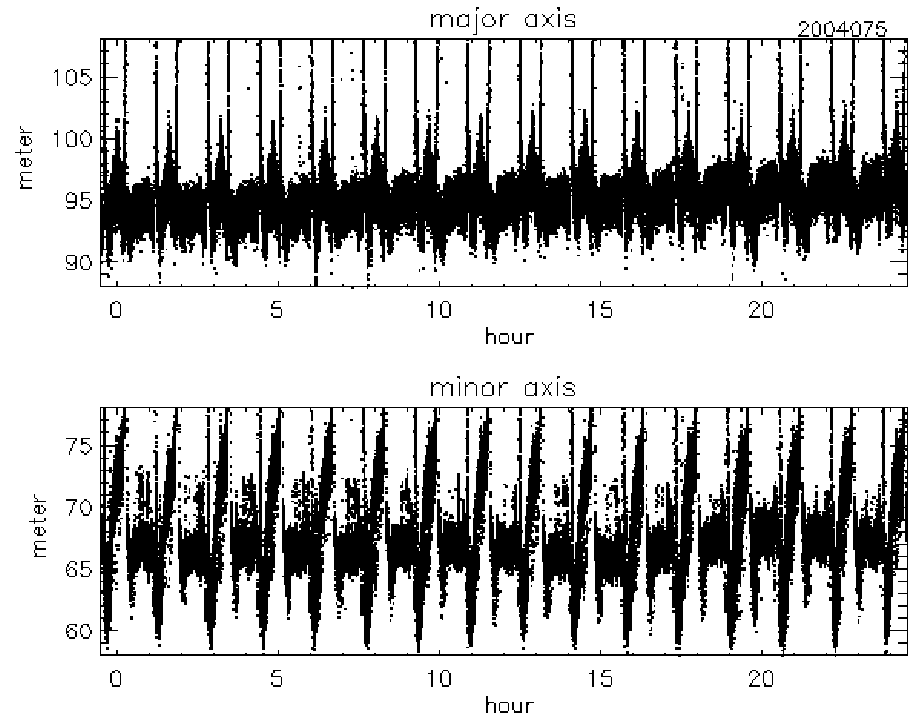


Stacking or averaging LPA images, to improve S/N to get a result for periods of low transmit energy, smooths the noise and the oscillations.

LPA (40 Hz)



LRS



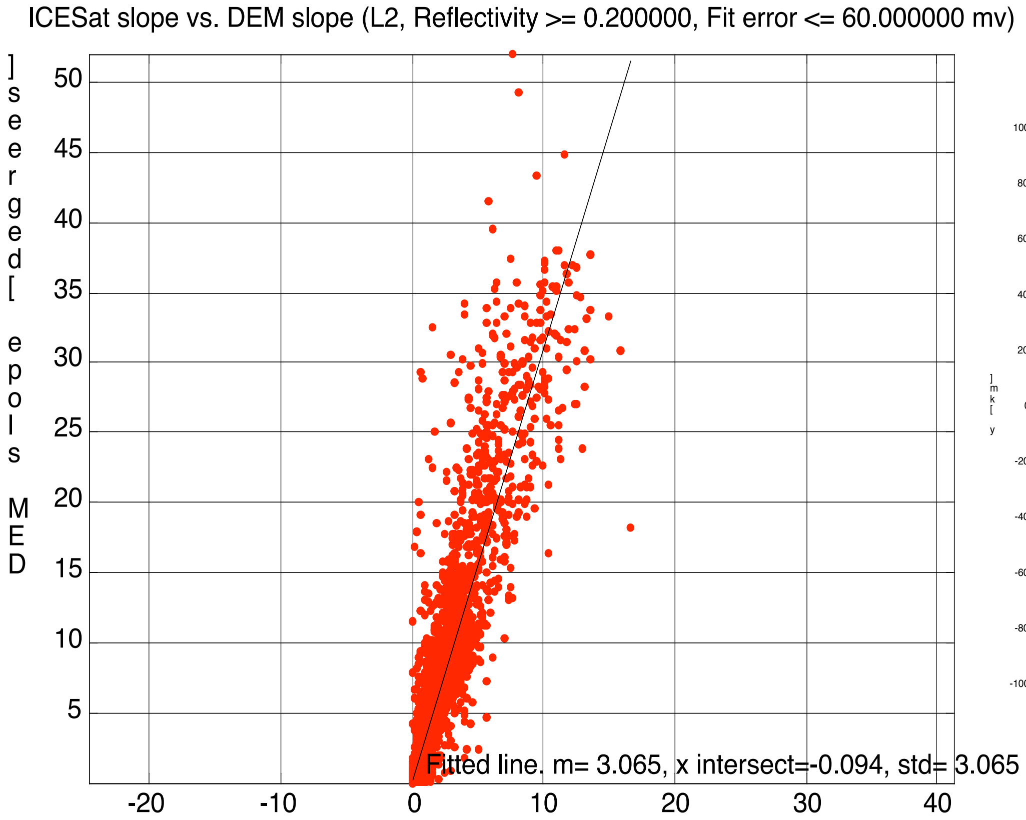
LPA and LRS both show systematic footprint diameter changes per orbit rev.

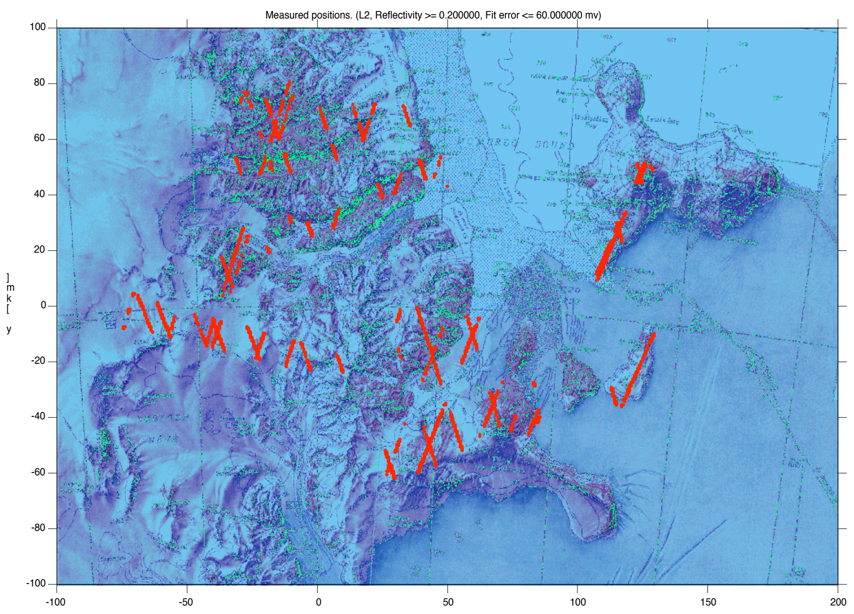
Task 10 - Slope and Roughness Estimation from Waveform Broadening

Leaders:	D. Yi and D. Harding
Primary Focus:	Ice sheet slope estimate (assumes no roughness) and roughness estimate (assumes no slope)
Approach:	Compare GLA slope and roughness products to surfaces with independently known slope and roughness
Status:	Major error in slope product identified Input parameters to Waveform ATBD slope algorithm revised Revision validated using off-pointing data to inland water (surrogate for slope)
Remaining Work:	Validate slope algorithm using round-the-world scans across Antarctica Assess slope estimation along slope azimuth in relation to elliptical footprint Assess FOV shadowing effect on slope estimation Implement slope derivation in GSAS code and validate (replacing constant footprint size currently used) Conduct same work for roughness product Assess slope and roughness accuracy using high-res airborne DEMs Document derivation methods and accuracy of results
Schedule:	Complete revision and validation of algorithms for slope and roughness by 12/05 Implementation in GSAS code depends on availability of Task 9 footprint ellipticity and size

ICESat slope vs. ATM Dry Valleys slope

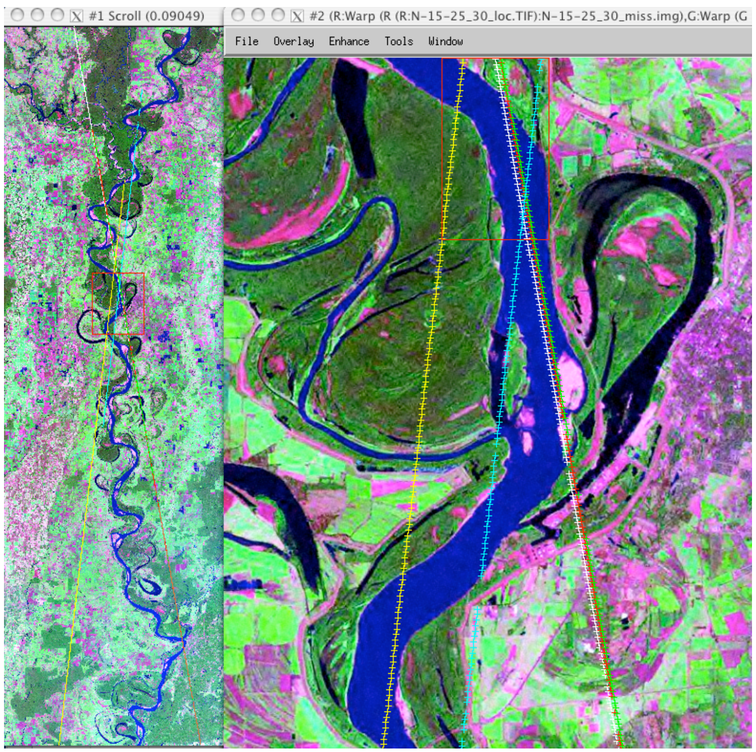
From Bea Csatho

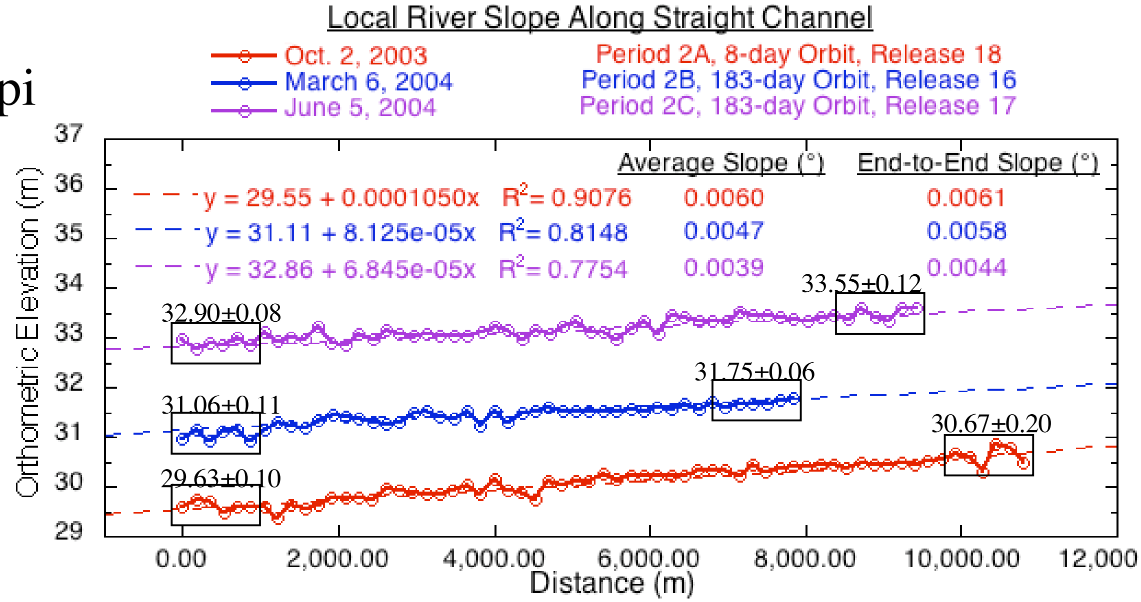




Slope Error Confirmation

Use off-nadir profiles targeted on flat, smooth reach of the Mississippi River to validate within-footprint estimates of slope.



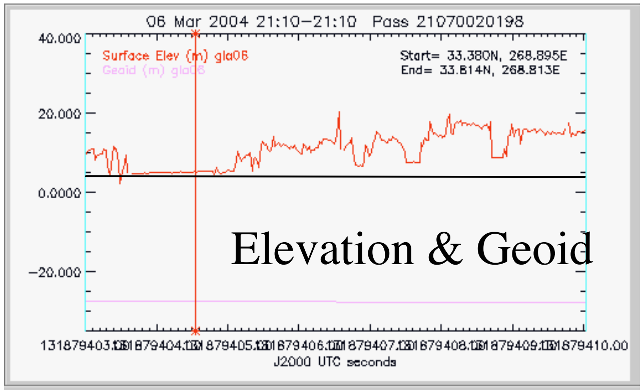


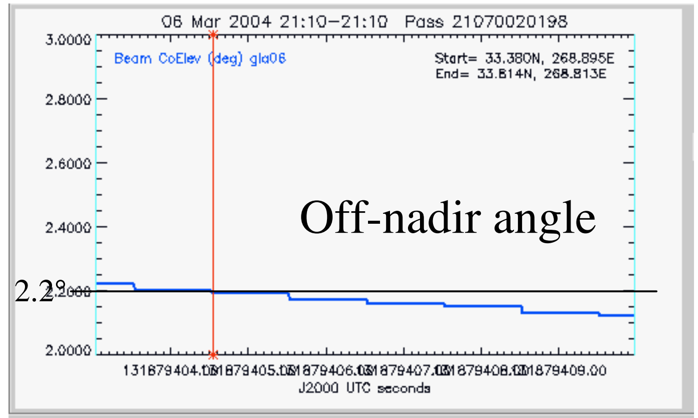
Surface water slope is very low (1 m in 10,000 m)

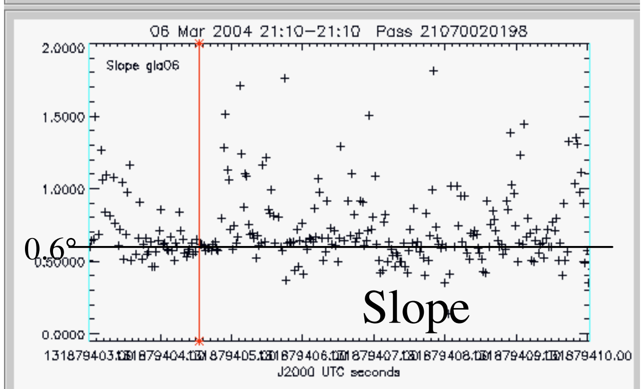
Surface water roughness is very low (shot-to-shot elevations vary by ~10 cm st. dev.)

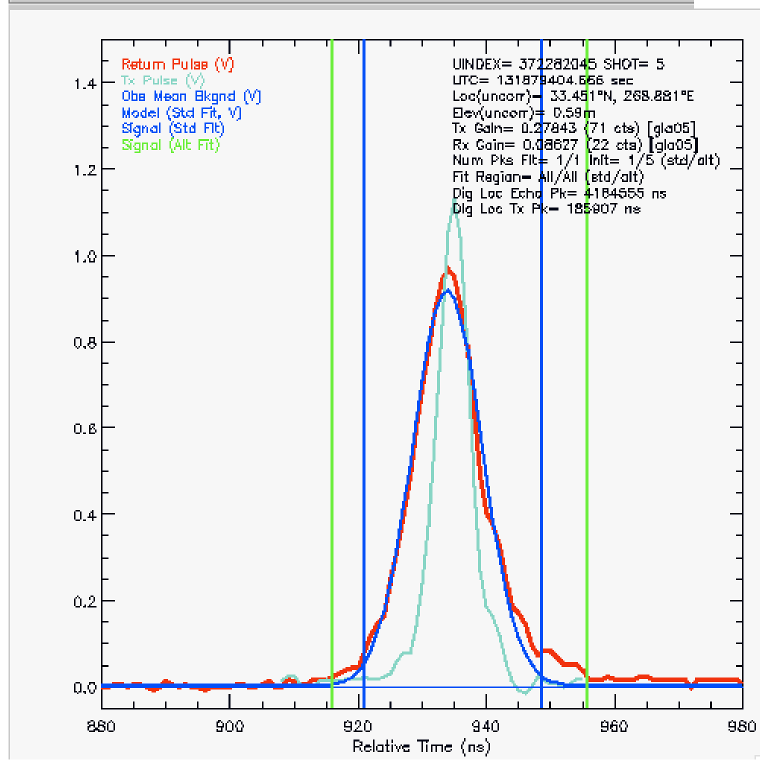
L2b 91-day Track 198 2.2° Off-Nadir Pointing at Smooth Mississippi River Reach

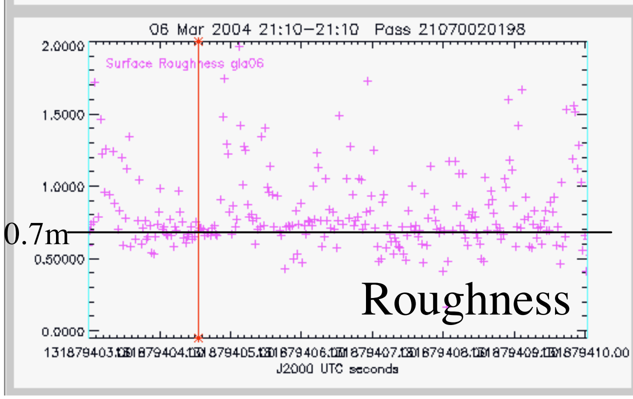
GLA Release 16 slope should be 3.7x larger than the reported value of ~0.6°











Waveform ATBD Slope Equation

The slope equation from the ATBD (Eq. 14) is

$$S = \tan^{-1}\left[\frac{c}{2z\tan q_T}\left(E(s_P^2) - (s_l^2 + s_h^2)\right)^{1/2}\right]$$

where (based on J. Saba and my interpretation of the ATBD):

S = surface slope
c = speed of light
z = satellite altitude
q_t = half width divergence angle of the laser beam
$E(S_p)$ = RMS width of the received pulse
S_l = RMS pulse width of transmit pulse
S_h = pulse width of the impulse response of the receiver

Putting this in terms of GLAS product variables (all on GLA05):

q_t = 0.00011 rad (constant in anc07)
$E(S_p)$ = i_parm2(n,i) = sigma (.01ns) of the n^{th} gaussian (maximum amplitude) for shot i
S_l = i_parmTr(4,i) = sigma (.01ns) of the gaussian fit to the transmit pulse
S_h = 1.7 ns = (constant in anc07)

The satellite altitude is computed using:

z = c (i_refRng + i_thRtkRngOff2) / 2

i_refRng = the reference range (.01 ns)
i_thRtkRngOff2 = standard fit threshold retracking range offset (.01ns)

Problem 1: constant beam divergence being used
Solution: use LPA or LRS images to measure actual divergence

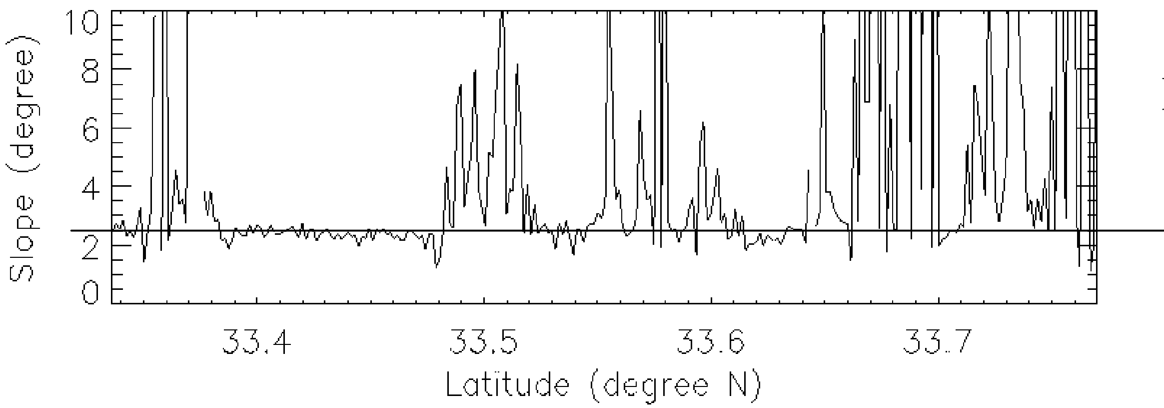
Problem 2: divergence constant used is too large
Solution: use 1 sigma diameter from image ($1/e^2$ diameter / 4)

Problem 3: footprint is not circular
Solution: use RMS of major and minor axes as an approximation, or
use diameter in the direction of the slope azimuth (if known)

Problem 4: transmit pulse waveform already includes receiver impulse response broadening
Solution: set S_h to 0

8-day Track 64 over Mississippi River, Laser 2a, Cycle 29

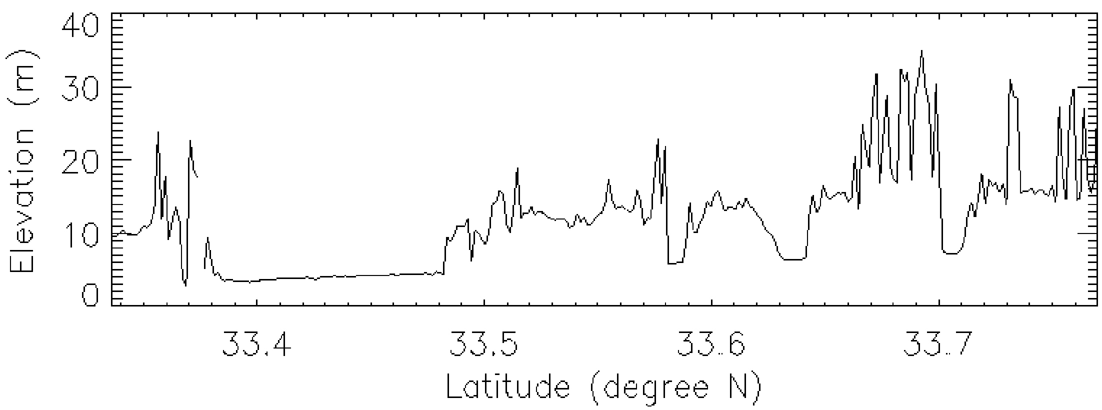
Footprint diameter (1-sigma) = 7.8 arc sec (RMS of IDL Gauss2dfit major and minor axes)
(from GLA04_019_1102_029_0063_0_01_0001.P0255)
Calculated slope using sigmas of Gaussian fits to transmit and receive (standard fit) waveforms
(from GLA05_021_1102_029_0063_4_01_0001.P0255)



From Donghui Yi

2.5° off-nadir pointing angle and 2.5° computed slope agree!

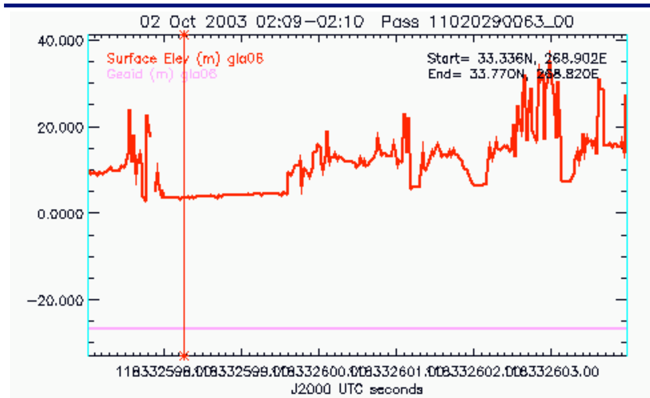
Issue 1: footprint during early L2a is very elliptical and has large FOV shadowing, so its hard to do a direct validation.

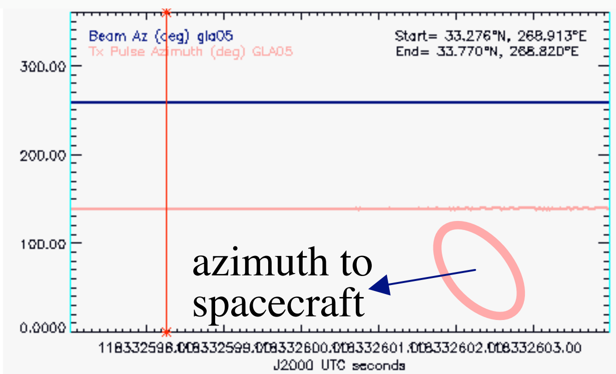


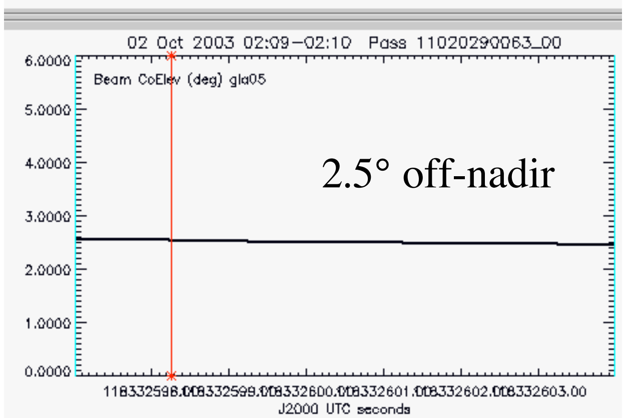
Issue 2: Estimation of slope and roughness from pulse spreading is only valid for planar surfaces.
—> Use alternate fitting to identify single-peaked waveforms and report results only for those.

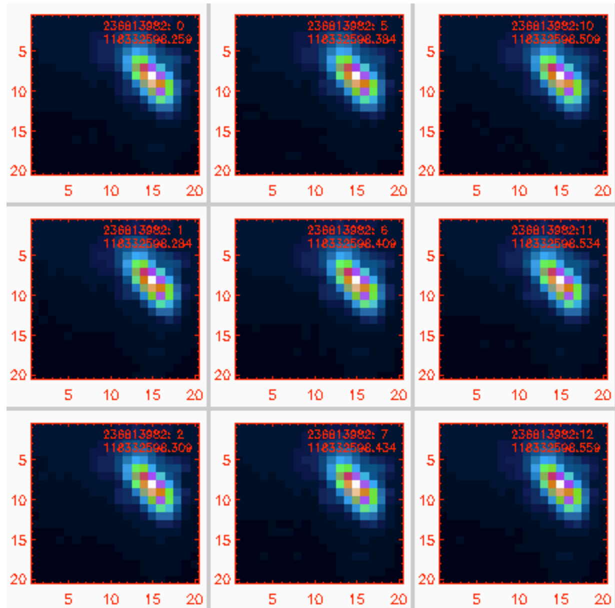
8-day Track 64, Laser 2a, Cycle 29, Release 21

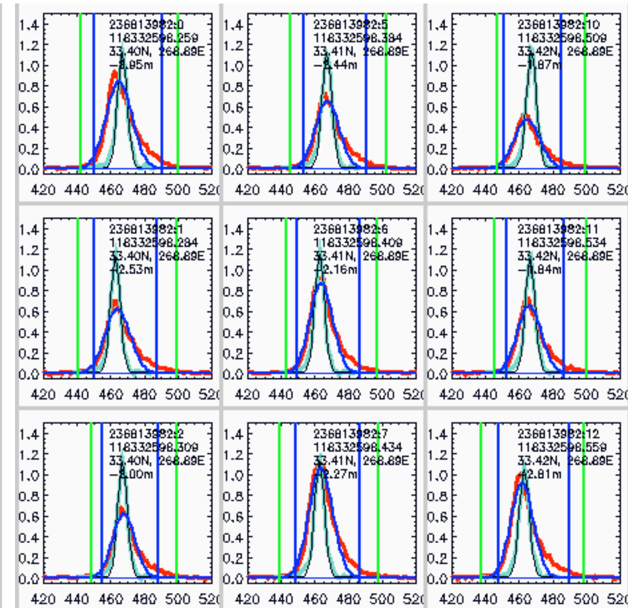
GLA01_021_1102_029_0063_4_01_0001.P0255

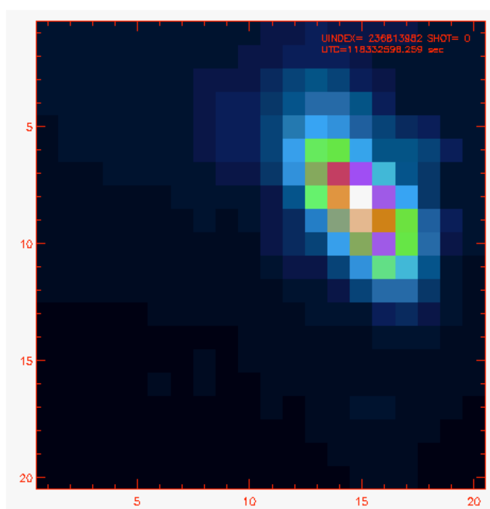


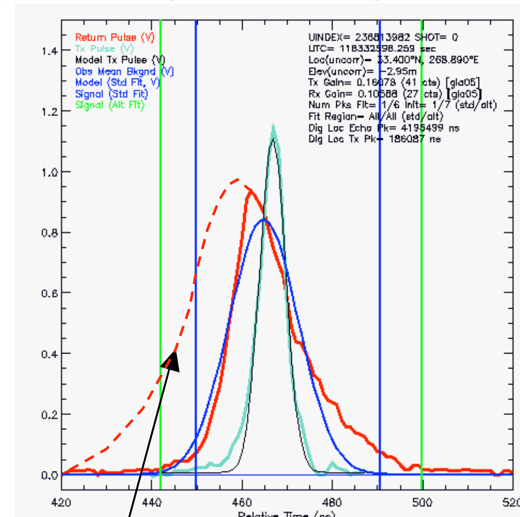












Unknown amount of leading edge truncated due to FOV shadowing causing waveform skew and underestimate of received echo width

Next Steps

More comprehensive slope validation will be done with data having less FOV-shadowing using Antarctica round-the-world scans, inland water pointing, and nadir tracks across DEMs

Effect of FOV-shadowing will be assessed

Assess slope estimation along slope azimuth in relation to elliptical footprint

Proposed Documentation Procedures

(D. Harding suggestions to initiate discussion)

ATBD Recommendations

- For revised products, update theory & implementation sections
- Add citations to relevant recent papers, including those in the GRL series
- Post all updated ATBDs at UT web site
- Mirror all ATBDs at WFF and NSIDC web sites
- When finalized, publish as NASA Technical Memorandum

Product Validation Recommendations

- Produce PDF documents (e.g., by Task Leaders for each PRD Task) containing:
  - Validation methods and results
  - Product accuracy assessment
  - Guidance to users on appropriate use
  - Citations to relevant ATBDs and papers
- Documents in chart format with figures and bulletized text

Product Format Web Page Recommendations

- On Variable pages include links to applicable ATBDs and Validation PDFs
  - Placed somewhere at the top so you do not have to scroll down to see them
- On GLA Product Format pages include column(s) on validation status
  - Release # when it was validated and method used (e.g., by inspection, analysis, or measurement)
  - Placed somewhere on left side so you do not have to scroll to the right to see it

Variable Definition Web Page

Display Variable

http://wffglas.wff.nasa.gov/v43_products/home.html?ht_action=var_view&ht_obj_key=3766

News (970) NASA Mac Weather Reference Search Andaman Mars Photogaphy traffic Apple (181)

NASA GSFC/Wallops Flight Facility
GLAS Software Development Database

Version 4.3
Display Variable
i_wfFitSDev_1

Last Modified : Thu Mar 27 13:43:00 GMT-0500 (EST) 2003 by lockwood

ID	i_wfFitSDev_1
Name	The received echo fit standard deviation (alternative)
Is Correction?	NA
Prod Variable Type	i2b
Unsigned	No
Prod Dimension 1	40
Prod Dimension 2	1
Prod Minimum Value	0
Prod Maximum Value	3000
Is a Flag	No
Invalid Value	i2b
Prod Units	millivolts
Alg Variable Name	d_wfFitSDev_1
Alg Variable Type	r8b
Alg Dimension 1	40
Alg Dimension 2	1
Alg Units	volts
Alg Scale	0.001
Special Conversions?	NA
A2P Conversion	null
P2A Conversion	true
Description	The standard deviation of the difference between the functional fit and the received echo using alternative parameters.
Comment	Note that the received echo was calibrated and converted from counts to voltage using table in header records before the fit was performed.

GLA Product Format Web Page

GLA05 Product Format

http://wffglas.wff.nasa.gov/v43_products/home.html?ht_action=view_format&ht_obj_key=14

News (970) NASA Mac Weather Reference Search Andaman Mars Photogaphy traffic Apple (181)

NASA GSFC/Wallops Flight Facility
GLAS Software Development Database

Version 4.3
GLA05 Product Format
Click on the Short Name to see full details regarding the selected field.

Return to Product Description | Return to List | Return to Main

Data Type Hint: i2b = 2 byte integer, i4b = 4 byte integer, r4b = 4 byte real, etc

Record Type	GLA05_MAIN	% of Granule	100	Record Duration (seconds)	1	Repeats	1

This record type contains the following variables...

Last Modified : Wed May 11 11:45:15 GMT-0400 (EDT) 2005

Product Var Name	Short Description	Offset (Bytes)	Product Data Type	Total Bytes	Product Units	Product Minimum	Product Maximum	Is Correction Flag?	Is Unsigned?	Invalid Value/Flag	Algorithm Var Name	Algorithm Data Type
i_rec_ndx	GLAS Record Index	0	i4b	4	N/A	0	2147483647	NA	No	no	i_rec_ndx	i4b
i_UTCTime	Transmit Time of First Shot in frame in J2000	4	i4b (2)	8	seconds, microseconds	0	2147483647	NA	No	no	d_UTCTime	r8b
i_transtime	One way transit time	12	i2b	2	microseconds	0	4000	NA	No	i2b	d_transtime	r8b
i_spare1	i_spare1	14	i1b (2)	2	NA	null	null	NA	No	no		
i_deltagpstmcor	Delta GPS time correction	16	i4b	4	nanoseconds	0	1000000	NA	No	gi_invalid_i4b	d_deltagpstmcor	r8b
i_dShotTime	Laser Shot Time Deltas (shots 2-40)	20	i4b (39)	156	microseconds	0	1200000	NA	No	No	d_dShotTime	r8b (39)
	Spot											